Modular Machinery Arrangement and Its Impact in Early-Stage Naval Electric Ship Design

by

David J. Jurkiewicz

Bachelor of Science in Mechanical Engineering
The George Washington University, 2007

Submitted to the Department of Mechanical Engineering
In Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Naval Architecture and Marine Engineering
and
Master of Science in Mechanical Engineering

at the

Massachusetts Institute of Technology

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ABSTRACT

Electrical power demands for naval surface combatants are projected to rise with the development of increasingly complex and power intensive combat systems. This trend also coincides with the need of achieving maximum fuel efficiency at both high and low hull speeds. A proposed solution to meet current and future energy needs of conventionally powered naval surface combatants is through the use of an Integrated Power System (IPS), which is seen as the next evolution in naval ship design. Unfortunately, historically-based ship design process models and parametrics cannot accommodate new-concept designs that are not incremental changes to previous practice. Additionally, integrating IPS with the next generation of ship designs is also synonymous with the desire of conducting system-level tradeoffs early within the ship design process. In an effort to enhance the relationship between new-concept designs and historically-based ship design processes, this thesis focuses on a novel approach of incorporating IPS at the earliest stage of the design process as part of assessing system-level tradeoffs early.

This thesis describes a methodology for the system design and arrangement of an IPS machinery plant based on an objective of meeting a desired power generation level, effectively introducing a power constraint at the start of the design process. In conjunction with the methodology development, a hierarchical process and design tool for integration with Graphics Research Corporation's (GRC) naval architecture software suite, Paramarine, is also produced to assist in rapid development and evaluation of various IPS arrangements. The result of this process, through several case studies, provides insight into equipment selection philosophy, the initial sizing of the ship's machinery box, and the initial definition of electrical zones. Lastly, the developed tool is also used to aid in the creation of "design banks," allowing the naval architect to manage weight, power, and volume at the beginning of the ship design process; therefore, supporting early system-level tradeoffs for new-concept designs.

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Table of Contents

List of Figures

List of Tables

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LIST OF ABBREVIATIONS

AC	Alternating Current
AMR	Auxiliary Machinery Room
ASSET	Advanced Ship and Submarine Evaluation Tool
CAB	Cable
CSDT	Cooling System Design Tool
DC	Direct Current
DDS	Design Data Sheet
ESM	Energy Storage Module
ESSDT	Early Stage Ship Design Tool
ESWBS	Expanded Ship Work Breakdown Structure
FIL	Filter
GE	General Electric
GEN	Generator
GT	Gas Turbine
HFAC	High Frequency AC Power
HM&E	Hull, Mechanical, and Electrical
IPS	Integrated Power System
IPSDM	Integrated Power System Design Module
kW	Kilowatt
MMR	Main Machinery Room
MOT	Motor
MS	Microsoft
MVAC	Medium Voltage AC Power
MVDC	Medium Voltage DC Power
MW	Megawatt
OMR	Other Machinery Room
PCM	Power Conversion Module
PDM	Power Distribution Module
PGM	Power Generation Module
PM	Prime Mover
PMM	Propulsion Motor Module
PPF	Propulsion Percentage Factor
RPM	Revolutions Per Minute
SFC	Specific Fuel Consumption
SS	Ship Service
SWATH	Small Waterplane Area Twin Hull
SWB	Switchboard/PCM
VAC	Voltage Alternating Current
VDC	Voltage Direct Current

ZEDS	Zonal Electric Distribution System

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1. INTRODUCTION

This thesis is intended to enhance the ship design process by applying a new design process rooted in principles of naval architecture, marine engineering, and mechanical engineering to new-concept ship designs. The focus of the application is on both current and future Integrated Power System (IPS) power generation and propulsion architectures. A novel methodology is proposed to present new insights into the historical ship design process of meeting the requirements of new-concept ship designs. The primary research objective was to implement the novel methodology by constructing an IPS design tool, the IPS Design Module (IPSDM), to aid the ship designer in systematically selecting and arranging IPS architectures at the start of the ship design process.

1.1. ORGANIZATION OF THESIS

The description of the IPSDM design process is presented in the following five chapters: Introduction, Methodology, Implementation, Case Study, and Conclusions. The Introduction provides background related to the historical ship design process, and introduces the purpose and the motivation for new-concept designs to utilize IPS. The Methodology chapter introduces the purpose of IPSDM, discusses the overall IPSDM design process, and defines the assumptions and equipment hierarchy inherent in the process. The Implementation chapter describes the fundamental elements of IPSDM in the selection and arrangement of equipment as well as metrics for assessing the design. The Case Study chapter demonstrates the outputs and use of IPSDM by comparing two notional IPS designs of the same power generation goal tailored to a medium-size surface combatant. The comparison of both architectures demonstrates the impact of evaluating system-level tradeoffs. Lastly, overall conclusions and identification of future work is presented to summarize the goals and impacts of the process.

1.2. BACKGROUND

Ship design can employ many types of design processes including set-based, genetic algorithms, and design spirals. Set-based design methods allow the complexity of the ship design effort to proceed concurrently, deferring detailed ship specifications until the design tradeoffs are understood (Singer, Doerry, & Buckley, 2009). Genetic algorithms simulate the evolution process in generating new ship designs, and learn from previous designs in an effort to move toward a more optimal design (Neti, 2005). However, the most fundamental ship design process in naval architecture is the historical ship design spiral. The historical ship design spiral is the classical approach to ship design, and is well understood within the naval architecture community.

Naval ship design also employs many types of system architectures including IPS. IPS is an emerging system architecture, rapidly gaining interest as shipboard energy demands play an increasing challenge to the design of naval ships. Incorporating IPS into new-concept naval ships within the historical ship design process is also a challenge, and recognizing the relationship of between the historical ship design process and IPS has led to the motivation of altering the historical ship design process in an attempt to incorporate IPS earlier in the ship design process.

1.2.1. HISTORICAL SHIP DESIGN PROCESS

Ship design is an iterative process, and typically depicted in a notional spiral as seen in Figure 1-1.

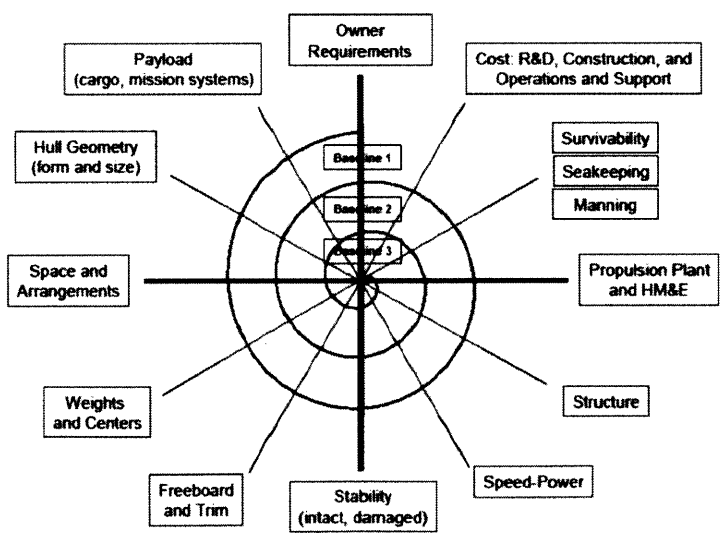

Figure 1-1: Notional Ship Design Spiral (Gale, 2003)

Design iterations can take place within each design section (i.e. hull geometry, space and arrangements, etc.) or globally as a single baseline (i.e. baseline 1, baseline 2, etc.), which are products of the ship design spiral (Gale, 2003). The ship design spiral is also layered with independent and dependent variables. For example, the establishment of a hull geometry, an independent variable, is required to perform freeboard and trim, stability, speed-power, and seakeeping analyses which are dependent on the variables of the hull geometry.

These interdependencies often provide challenges throughout the design cycle. The challenges are frequently mitigated by the parameterization of historically-based ship design data. The use of parametrics allows the designer to estimate unknown areas within the early stages of the design process as a function of known independent variables, such as manning and payloads. These parametrics ultimately aid in determining the principal characteristics of the baseline design.

Another emphasis of the historical ship design process is to perform "system-of-systems" tradeoffs. A ship can be viewed as composition of subsystems operating in unison to perform a function greater than the sum of its parts. For a naval combatant, three major subsystems that comprise the ship are: the mission systems, propulsion system, and the hull, mechanical and electrical (HM&E) system.

The mission systems are defined as a composition of customer driven requirements, and are typically traded-off early in the design process as independent variables. As a result, the interdependencies of the ship design process are often affected by tradeoffs made of this system early in the design process. The mission system can be comprised of the radar systems, weapon systems, sonar systems, and helicopter systems.

The propulsion system is also a composition of customer requirements as a function of ship speed and range performance. Discrete equipment in the form of prime movers, reduction gears, and propellers are selected in order to meet customer requirements. The determination of the propulsion system, as depicted in Figure 1-1, is historically a derivative of hull geometry and overall ship size and configuration (Kinney & Funkhouser, 1987).

The HM&E systems are derivatives of both customer requirements and the propulsion system. HM&E systems can include auxiliary equipment such as fuel systems, cooling systems, and distilling systems to support both mission and propulsion systems. Ultimately, these systems support the overall function of the ship.

1.2.2. INTEGRATED POWER SYSTEM

Future naval ship designs are perusing the integration of propulsion and ship service electrical ship systems, further complicating the interdependences in the ship design process. Historical ship designs separate the propulsion system from the ship service electrical system. This "separation" design philosophy is also the foundation of current early stage ship design parametrics.

Nevertheless, commercial and naval sectors are pursing the integration of both propulsion and ship service electrical systems into a single system, IPS. The naval sector is driven to IPS by the projection of ship service power demands of future combatants armed with advanced weapons (e.g. railgun and lasers) and sensors (e.g. next generation radars) (NAVSEA, 2007). Figure 1-2 shows a depiction of the future demand.

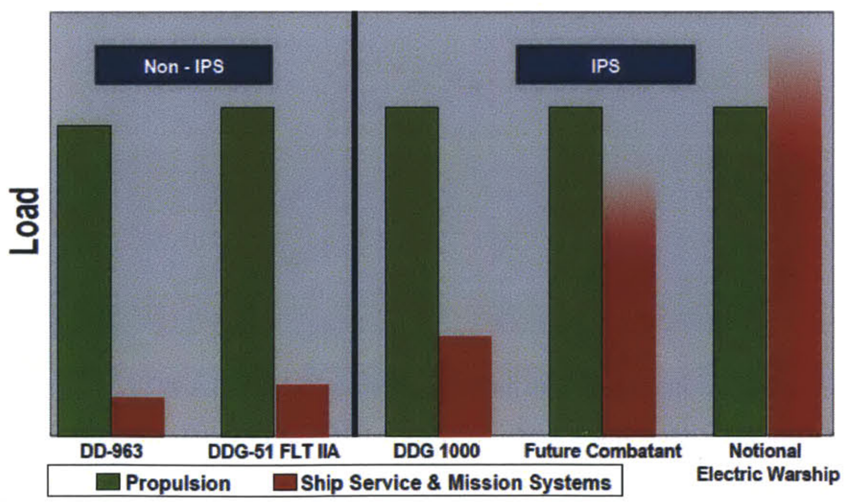

Figure 1-2: Future Ship Board Power Projections (NAVSEA, 2007)

With the future of increasing electrical demand fast approaching, the need for IPS becomes greater.

1.2.2.1. IPS BENEFITS

IPS incorporates power generation, propulsion, and ship service distribution into a single integrated system. The shift to IPS is also driven by the need to increase ship affordability, mission performance, and operability (N. H. Doerry & Davis, 1994). IPS also allows greater architectural flexibility in the ship design without the need to align the propeller shaft with the prime movers. Instead, propulsion motors can be coupled to the propeller shaft allowing the ship designer to position the prime movers in other areas of the ship. This enhancement permits the designer to increase ship survivability through separation and distribution (N. H. Doerry & Davis, 1994).

1.2.2.2. IPS DISTRIBUTION ARCHITECTURES

Utilizing IPS in naval ships also requires a new generation of distribution architectures. The new distribution architecture must accommodate the transfer of power from propulsion electrical loads to ship service electrical loads as well as the mitigation of faults cause by battle damage. Figure 1-3 depicts future areas of distribution architectures using IPS.

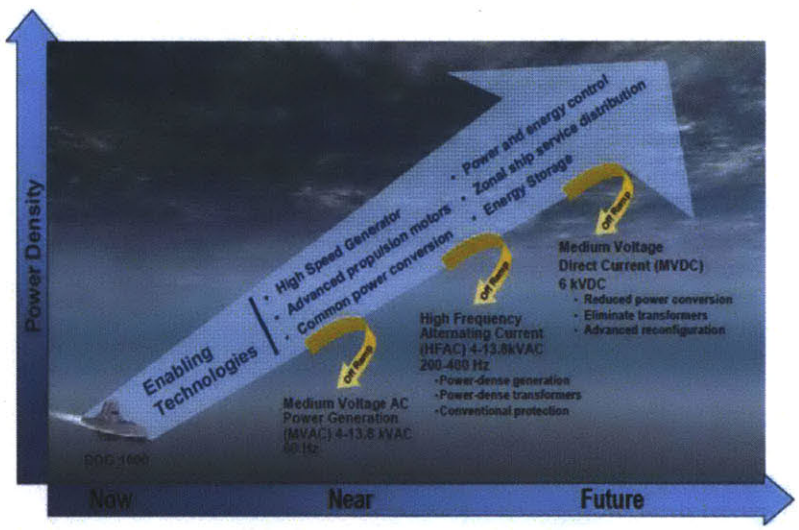

Figure 1-3: Distribution Roadmap (NAVSEA, 2007)

The definition of the following three architectures presented in Figure 3-4 is as follows (NAVSEA, 2007):

a) Medium Voltage AC Power (MVAC): power is generated as 3 phase 60 Hz at one of three standard voltages: 4.16 kVAC, 6.9 kVAC, or 13.8 kVAC. Distribution of power interfaces with a notional AC Zonal Electric Distribution System (ZEDS).
b) High Frequency AC Power (HFAC): power is generated at a fixed frequency greater than 60 Hz and less than 400 Hz at either 4.16 kVAC or 13.8 kVAC. Distribution of power interfaces with a notional AC ZEDS.

c) Medium Voltage DC Power (MVDC): power is immediately rectified from the energy source to DC, and is distributed with a notional DC ZEDS. Distributed voltages range from 1000 VDC to 10,000 VDC.

Utilizing the three architectures allows the ship design to effectively, safely, and efficiently integrate the mission system and the energy system. Figure 1-4 shows an example of a shipboard IPS schematic of a medium voltage system.

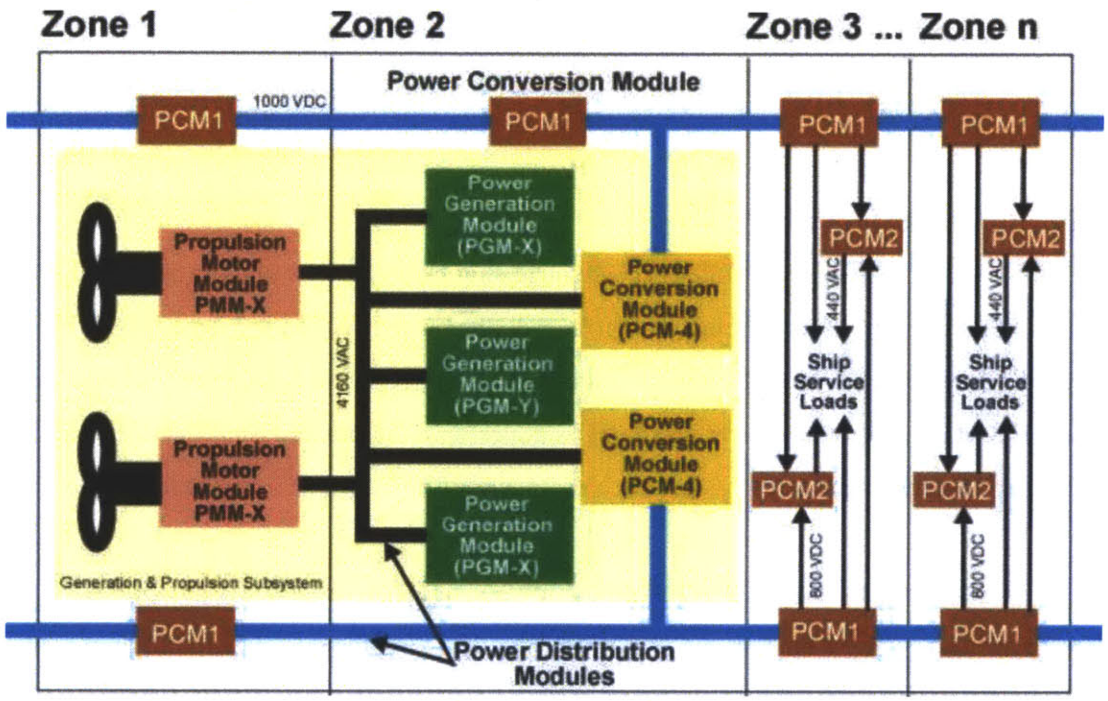

Figure 1-4: IPS Architecture and Modules (N. Doerry, Robey, Amy, & Petry, 1996)

1.2.2.3. IPS MODULARITY

As depicted in Figure 1-4, IPS is viewed as a composition of modules. These "families" of modules are utilized to create electrical distribution systems in the form of electrical power zones in either AC or DC voltage. The following families of modules for IPS are as follows (N. Doerry et al., 1996):

- PGM: Power Generation Module
    - Module includes prime mover, generator, and support modules
- PMM: Propulsion Motor Module
    - Includes lube oil service and control modules
- PDM: Power Distribution Module
    - Transfer power for ship service and propulsion

- ESM: Energy Storage Module
    - Improve system efficiency or system start-up (Holsonback, Webb, Kiehne, & Conner, 2001)
- PCM: Power Conversion Module
    - Convert, invert, and rectify power from AC-DC, DC-AC, AC-AC, DC-DC
- PCON: Power Control Module
    - Control the operation of IPS through control software (N. Doerry, 2008)

The modular approach of IPS allows the ship designer to select the appropriate modules in order to achieve the ship's electrical requirements.

1.3. MOTIVATION

The incorporation of IPS into the era of the electric ship provides new challenges to the ship design process. As ship service electrical power demands continue to increase, historically-based ship design process models and parametrics are not accommodating new-concept designs pursuing IPS. Conventionally-powered designs addressing the power issue that are not incremental changes to the previous practice require alternative models and parametrics.

However, the combination of propulsion and ship service electrical generation allows for more design flexibility at the earliest stages of design, thus allowing the designer to conduct system-of-system energy tradeoffs with the mission systems earlier in the ship design process, not typically accomplished in a conventional design (N. Doerry & Fireman, 2006). Overall the notional ship design process is fundamentally the same with IPS, but as depicted in Figure 1-5, the design process can be adjusted to incorporate the capability of IPS at the earliest design stages.

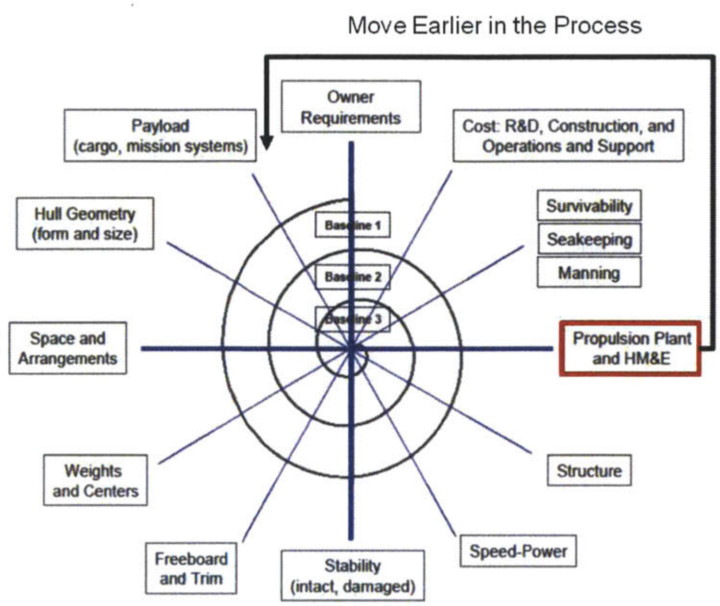

Figure 1-5: Alternate Design Spiral Modified from Gale, 2003

By addressing the energy requirement early in the ship design process, the ship design can in part revolve around the energy capability of the ship to meet energy demands of the customer requirements. This approach alters the interdependences between the design elements in the process, linking them to the independent variables of both mission and energy systems. In essence, the foundation of the baseline design is determined by the tradeoffs between energy systems, mission systems, and customer requirements.

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2. METHODOLOGY

The design of the propulsion and ship service electrical plant is typically fueled by constraints made earlier in the ship design spiral, as discussed in Section 1.2.1. The propulsion sizing and arrangement is largely driven by the hull form geometry and its performance via the speed-power curve, and the ship service electrical plant sizing and arrangement is largely driven by the mission system electrical loads. The methodology described in this chapter redefines the inputs and outputs of the typical ship design process utilizing IPS. It also highlights the overall assumptions inherent in the process and the establishment of a hierarchy of equipment required during the machinery arrangement process.

2.1. INTENT

The intent of this process is to provide the designer with the ability to make system-level tradeoffs and introduce system-level design constraints early the ship design process for a new-concept ship design. The process assumes the designer has a total "power requirement" in mind for both ship service electrical distribution and propulsion power demand and chooses IPS to achieve it. The power requirement serves as a constraint for the overall ship design, and allows the designer to make tradeoffs related to payload and ship characteristics as a function of power generation capacity. Introducing this constraint early in the process effectively establishes the capacity of the machinery plant as the basis for making various design decisions throughout the design cycle and can define the envelope of ship capabilities such as maximum speed. This process can allow the designer to optimize the ship design around the systems as part of an "inside-out" ship design process in the following areas:

- Power Generation
- Propulsion
- Power Distribution
- Thermal Management
- Arrangement

The output of this process is intended to be stored into database whereby pre-arranged IPS architectures can be selected in conjunction with mission systems to begin defining the overall principal characteristics of the ship as well as its capability.

In an effort to implement and demonstrate the usefulness of the process, IPSDM was developed. By developing IPSDM, further insight to the validity of the process was provided, and its usefulness further demonstrated through case studies. The output of IPSDM feeds into an Early Stage Ship Design Tool (ESSDT) provided by research conducted in parallel to this thesis titled *Development of an Early Stage Ship Design Tool for Rapid Modeling in Paramarine* by fellow 2012 Naval Engineer's degree candidate LT Eric J. Thurkins Jr, USN. The IPSDM output will initiate the remainder of ship design process by serving as a primary input into ESSDT. Ultimately, the IPSDM data, along with ESSDT's data, is fed into GRC Paramarine for further analysis.

2.2. IPSDM DESIGN PROCESS OVERVIEW

The proposed IPSDM design process is depicted in Figure 2-1. The arrows depicted in Figure 2-1 indicate the flow of information.

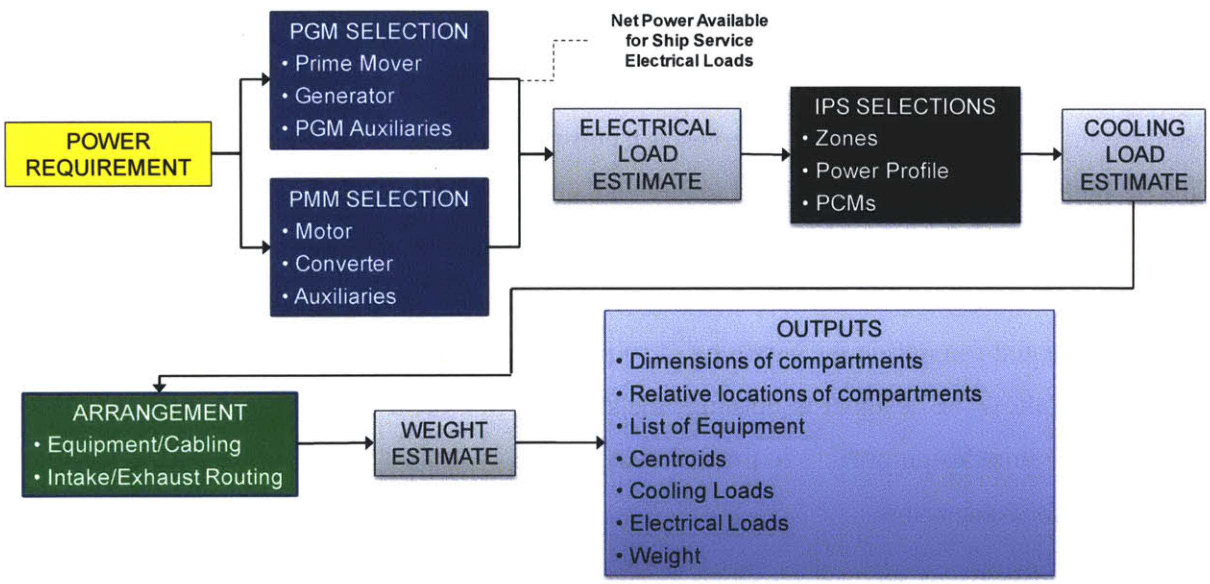

Figure 2-1: Proposed IPS Design Process

The design process outlined in Figure 2-1 is envisioned to be a linear process that primarily focuses on the selection and arrangement of propulsion and ship service electrical generation systems. The design process also identifies power distribution architectures, the estimation of electrical loads of auxiliary support systems, the estimation of thermal loads generated by the system, and the estimation of the overall weight of the system.

The initiation of the design process begins with the power requirement. The power requirement defines the output of the propulsion and ship service architectures. With the desired output established, equipment selections are conducted to achieve the desired outputs in the form of PGMs and PMMs. The selection of these modules effectively establishes the energy capacity and delivery capability of the IPS architecture in the form of propulsion and ship service electrical loads. These modules are comprised of groups of equipment to support the overall operation of each module.

The support equipment within these modules also demands power in order to perform its operation. With the demand known, a preliminary electrical load assessment can be conducted to determine the total electrical load demand of the auxiliary equipment. The electrical load assessment becomes an input for further analysis when combined with mission systems and their electrical load requirements. This information is used to reduce the overall power available for distribution in order to determine a net power available for mission systems. The revised power available for distribution is compared against the power requirement.

Once the selection of the PGMs and PMMs satisfy the power requirement, a distribution system, number of electrical zones, and location of electrical zones can be identified. Within the distribution systems, additional modules are required in the form of rectifiers, transformers, and invertors to condition and distribute power via a distribution architecture described in Section 1.2.2. With the PGMs, PMMs, and distribution systems known, a thermal load analysis can be conducted to assess the preliminary cooling system requirement for the chosen systems. This assessment becomes an input for further analysis when combined with the mission systems and their cooling requirements.

When all power requirements and equipment selections have been satisfied, the arrangement of the equipment and identification of service highways can take place. The output of the arrangement identifies the location of all equipment, overall dimensions of the entire system, and the finalization of the weight estimate, concluding the design process.

The outputs of IPSDM provide insight and design constraints throughout the remainder of the ship design process. After merging the outputs from this process and the selection of desired mission systems, can the overall capability of the ship can be assessed and compared against the customer requirements.

2.2.1. OVERALL ASSUMPTIONS

The purpose of identifying the assumptions is to highlight the need of the ship designer to be cognizant of the relationship between the complete ship design process and IPS architectures. The decisions made in the construction of the clean-sheet IPS design are drivers the remainder of the total ship design.

Specific assumptions related to each area of IPSDM (e.g. PGM selection, PMM selection, electrical load estimation) are identified in their respective sections within Chapter 3; however, there are assumptions inherent to the total IPSDM design process. The assumptions are in the context of a clean-sheet IPS design whereby an individual follows the steps of the design process as described in Section 2.2. The assumptions to the process are as follows:

1. Database content
    a. The machinery plant design process is always tied to an equipment database (Kinney & Funkhouser, 1987). The individual must be familiar with the database in order to conduct a clean-sheet IPS design. If the information related to the equipment in the database is greatly uncertain, then outputs of the process will carry the uncertainty throughout the remainder of the ship design process. Understanding the sources of uncertainty can aid in the determination of design margins within the ship design process.
2. Knowledge of IPS and its composition
    a. Executing the process requires the individual to be familiar with the various IPS architectures, such as those described in Section 1.2.2, and their required components to accurately reflect the desired architecture. Understanding the number and types of equipment for IPS affects the performance of the overall system in meeting the power requirement.
3. Knowledge of ship arrangements and naval architecture

a. To effectively arrange the equipment, one must understand the impacts of the arrangement relative to the compartment and the total ship design. For example, within the compartment, identifying and locating redundant systems can play a role in the overall system operation in instances of routine maintenance and recoverability from damage.

2.2.2. EQUIPMENT DEFINITION HIERARCHY AND DEPENDENCIES

The IPSDM process relies on a database of equipment and its arrangement in order to feed data into the remainder of the ship design process. In order to effectively select and arrange the equipment, IPS was decomposed into three main areas. The three proposed areas are: Power Generation, Propulsion, and Distribution. Decomposing IPS to these areas introduces the level of fidelity the IPSDM design process requires in order to compute a sufficient and meaningful output. The three IPS areas can be decomposed further into the hierarchy depicted in Figure 2-2. The entire decomposition is derived from the research into existing ship machinery spaces and existing ship design tools such as the US Navy's *Advanced Ship and Submarine Evaluation Tool (ASSET)*.

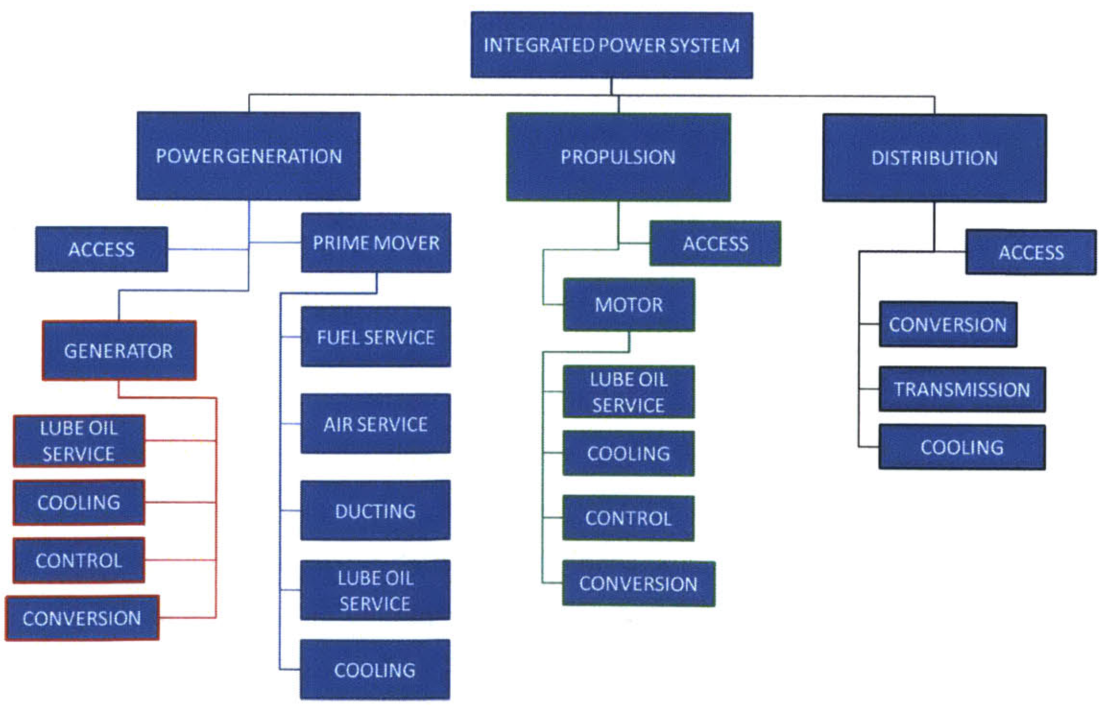

Figure 2-2: IPS Decomposition

Within each area, equipment is further decomposed to indicate dependency within the hierarchical chain. Equipment located below the prime mover, generator, and motor main equipment items in Figure 2-2 are defined as auxiliaries. These auxiliaries are required to support the operation of the main equipment items.

2.2.2.1. POWER GENERATION

The largest of the three functional IPS areas is Power Generation. Power Generation includes two main equipment items: the prime mover and generator. Each item requires additional auxiliary equipment to support its operation in the system as depicted in Figure 2-2. The following list defines the auxiliaries for the prime mover and generator.

- Prime Mover: energy source (e.g. gas turbine engine, diesel engine, fuel cell, etc.)
    - Fuel Service: pumps and purifiers associated with providing and conditioning fuel to the prime mover
    - Air Service: pumps and compressors associated with providing air to start the prime mover
    - Ducting: intake and exhaust for prime mover
    - Lube Oil Service: pumps and purifiers associated with providing and conditioning lubrication to the prime mover
    - Cooling: equipment using an air or liquid medium to remove heat from the prime mover and auxiliary equipment
- Generator: convert mechanical energy to electrical energy
    - Lube Oil Service: pumps and purifiers associated with providing and conditioning lubrication to the generator
    - Cooling: equipment using an air or liquid medium to remove heat from the generator and auxiliary equipment
    - Control: equipment required to regulate the output of the generator
    - Conversion/Distribution: condition power for distribution in the form of switchgears or PCMs for ship service and propulsion electrical loads

Each auxiliary instance is assumed to be function of the number of generators and prime movers selected in the IPS design process.

2.2.2.2. PROPULSION

Propulsion is the second largest of the three functional IPS areas. The main equipment item within propulsion is the propulsion motor. The propulsion motor can comprise the spectrum of large induction motors to small azimuth podded propulsors. Each propulsion motor also requires auxiliaries to support the overall operation of the propulsion system similar to the prime mover and generator. The following list defines the auxiliaries for the propulsion motor:

- Motor: deliver mechanical power to propulsor (e.g. propeller, waterjet, etc.)
    - Lube Oil Service: pumps and purifiers associated with providing and conditioning lubrication to the motor and/or braking resistors
    - Cooling: equipment using an air or liquid medium to remove heat from the motor and auxiliary equipment
    - Control: equipment (e.g. power filters and braking resistors) required to regulate the power input and output of the motor
    - Conversion: condition input power from ship distribution system through PCMs for motor use

Also, each auxiliary instance is assumed to be function of the number of motors selected in the IPS design process.

2.2.2.3. DISTRIBUTION

Distribution is the most flexible system of the three functional areas because it is comprised of smaller specialized items that condition and isolate power from the power generation system. The distribution system can also comprise of different architectures as described in Section 1.2.2. The distribution system is the key enabling concept for IPS as it can be divided into zones that comprise of individual or multiple ship compartments (Hawbaker, 2008). Separating the electrical system into zones allows the ship's electrical grid to isolate power in the advent of faults caused by an event (i.e. damage). The equipment composition of distribution is as follows:

- Conversion: condition input power for ship distribution system use through PCMs. Several PCMs are further defined by the 2007 *NGIPS Technology Development Roadmap*:
    - *PCM-4: Transformer Rectifier to convert MVAC power to 1000 VDC power. The rating of the PCM-4 must be greater than 1/2 of the maximum margined electrical load and greater than the total un-interruptible load. Under normal operation,*

two PCM-4s will be operational, each supplying power to one of the port / starboard longitudinal busses.

  - *PCM-1: Converts 1000 VDC Power from PCM-4 to 800 VDC power, 650 VDC Power, or another user-needed DC voltage. Also segregates and protects the Port and Starboard 1000 VDC Busses from in-zone faults. 650 VDC Power used to supply power to motor controllers for large motors and for large resistive heating applications PCM-1 contains a number of modular Ship Service Converter Modules (SSCM) that can be paralleled to provide redundancy and the requisite power rating. Each SSCM currently has a rating of 300 kW and uses a proprietary interface with the PCM-1 cabinet. SSCMs can provide power to segregated outputs. For each segregated output, with one SSCM out of service, the remaining SSCMs shall be able to supply the greater of 50% of the maximum margined load or 100% of the maximum margined un-interruptible load serviced by that segregated output. (The 2nd PCM-1 in the zone will supply the other 50% of the load)*
  - *PCM-2: Converts 800 VDC power from PCM-1 into 450 VAC Power at 60 Hz. or 400 Hz. Although a zone may have multiple PCM-2s, cost savings can be realized by limiting the number of PCM-2s necessary to achieve survivability requirements. PCM-2 contains a number of modular Ship Service Inverter Modules (SSIM) that can be paralleled to provide redundancy and the requisite power rating. Each SSIM currently has a rating of 300 kW and uses a proprietary interface with the PCM-2 cabinet. SSIMs can provide power to segregated outputs. For each segregated output, with one SSIM out of service, the remaining SSIMs shall be able to supply the maximum margined load serviced by that segregated output.*
- Transmission: distribute electrical power through cabling via port and starboard buses throughout the ship as part of service highways.
- Cooling: equipment using an air or liquid medium to remove heat from the electrical distribution equipment

Each PCM plays a vital role within IPS, and number and location of this equipment can be a function of both power generation and propulsion areas. The following list identifies the equipment and its dependency:

- PCM-4: a function of the number of generators or the number of buses (i.e. port and starboard) within the ship.
- PCM-1: a function of the number of zones and buses
- PCM-2: a function of the number of zones; however, actual number can vary within zone depending on zonal power capacity and equipment within each zone.

The rationale behind the dependences is derived from varies distribution architectures within the 2007 *NGIPS Technology Development Roadmap* and LT Hawbaker, USN, 2008 thesis, *Analyzing the Effects of Component Reliability on Naval Integrated Power System Quality of Service*.

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3. IPSDM IMPLEMENTATION ELEMENTS

IPSDM, a tool implementing the proposed IPS design process outlined in Chapter 2, is a linear procedure developed to construct a desired shipboard IPS architecture. Appendix A, the IPSDM User Manual, describes the IPSDM Microsoft (MS) Excel-based program and its interfaces in detail. However, the purpose of this chapter is to discuss the major elements of IPSDM, as well as the methods IPSDM uses to addresses the areas of power generation, propulsion, distribution, thermal management, and arrangement. The major elements within IPSDM are identified as follows.

1. Planning
2. Equipment Selection
3. Electrical Load Analysis
4. Zonal Electrical Distribution Selection
5. Thermal Load Analysis
6. Machinery Arrangement
7. Weight Estimation
8. Output

The information within the element list above is crucial in executing the IPSDM; furthermore, understanding the major elements of IPSDM aids in the effectiveness of the design tool.

3.1. PLANNING

In order to effectively incorporate the assumptions of the IPS design process in Section 2.2.1, planning is required before making any equipment selections. The following sections identify two critical areas of planning: determination of the power requirement and the physical number and types of compartments devoted to IPS equipment. The power requirement is the most critical input to the process forming the basis for all equipment selection and subsequent analysis, determining quantity and compartments sizes of the IPS architecture.

3.1.1. POWER REQUIREMENT

The power requirement is the total maximum power estimate for a particular ship design. It is the sum of estimated propulsion power to overcome the effective power of the hull to achieve a maximum speed, and the estimated maximum electrical load required for ship service operations after subtracting the IPS auxiliary electrical loads. Section 3.3 defines the estimation of the IPS auxiliary electrical loads. The propulsion and ship service electrical values form the basis for all design decisions with regard to PGM and PMM selection. Establishing the power requirement allows the designer to conduct system-level tradeoffs early in the process and allows for the optimization of equipment to meet it. The power requirement will allow the designer to choose the required equipment and distribution it in an effort to size the ship's main machinery compartments.

The overall power requirement can be estimated from the following:

- An initial guess
- A value based on a particular number and type of PGMs
    - e.g. two Rolls-Royce MT30s and three Caterpillar 3512 diesel generator sets
- A value based on previous ship designs
    - e.g. DDG-51
- Achieving a maximum speed for a particular hull form
- Part of an iterative process where various stages of design data are available

In some cases, the desire to study a particular schema of PGMs will drive the power requirement, especially when comparing the schemata to other architectures. If this power requirement is an initial guess, it should be assumed to be the power required for maximum margined vital ship service electrical load and required propulsion power to achieve a desired speed. The available design data may take the form of effective power curves for a particular hull at a particular displacement, or the known value of a large electrical power consumer such as a large radar, electronic weapon, etc. The designer must understand the basis of the power requirement to make effective IPS design decisions further in the IPS design process.

Applying design margins and service life allowances for the estimated power capacity can also be determined at this stage if the power requirement is largely uncertain. The design margins and service life allowances are included into the total power requirement. Including the margins and allowances in the total power requirement distributes the uncertainty equally between propulsion and electrical power loads. If the power requirement is based on an existing ship, margins and allowances can be set to zero assuming they are accounted for in the total power requirement.

3.1.2. NUMBER AND TYPES OF COMPARTMENTS

Planning the number of compartments for the machinery equipment is important before selecting any equipment item. The number of compartments establishes one of the upper elements the machinery arrangement hierarchy, and essentially allocates the space early in the process where the equipment will eventually reside in the ship. The suggested limit on the total number of compartments is eight. This number is based on researching machinery plants of modern conventionally-powered naval ships and derived from references that recommend for ships greater than or equal to 120 meters to consider up to eight electrical zones for IPS (N. H. Doerry, 2005). The number of compartments also will form the basis of identifying electrical zones later in the process.

The type of compartment allows the designer to group equipment items together to perform a specific function as well as to separate items with transverse watertight bulkhead barriers. Based on historical nomenclature and nomenclature used in ship design tools such as ASSET, the three types of compartments suggested are defined as follows:

- Main Machinery Room (MMR): a compartment that contains equipment intended for ship propulsion such as large PGMs and PMMs. This compartment may contain other auxiliary components such as distilling plants and auxiliary engines, but shall remain MMRs should any PGM or PMM intended for propulsion be collocated in that compartment.
- Auxiliary Machinery Room (AMR): a compartment that contains equipment for support of ship service electrical power and any additional support equipment such as heat exchangers, air conditioning units, etc.
- Other Machinery Room (OMR): a compartment that contains equipment for support of ship service electrical power and support equipment such as heat exchangers that are separate from the MMR and AMR consecutive stack-up configuration. OMRs are machinery compartments allowing for user specified separation between the consecutive machinery compartments.

The intent was to minimize the number of compartment types such that the designer is not overwhelmed at the start of the design process. Determining the type and number of compartments allows the designer to better tailor equipment selections as a guide to constructing a particular IPS architecture.

3.2. EQUIPMENT SELECTION

The equipment selection quantifies the effectiveness of IPS in power generation, propulsion, and distribution. Equipment selection defines the energy capacity, delivery, and overall dimensions of IPS. It is the foundation of the IPS design and sequent analysis, and must be understood when executing IPSDM.

3.2.1. POWER GENERATION EQUIPMENT SELECTION

After establishing a power generation requirement and determining the initial number of compartments, the next step is to select the suitable combination of PGMs to meet the desired total power generation requirement and place them into the appropriate compartments. The larger the number of PGM options available, the closer the designer is able meeting the power requirement with discrete combinations. The selection of PGMs is at the discretion of the designer's philosophy for meeting a particular power requirement. Examples of design philosophies that influence PGM selection to achieve the power requirement might include but are not limited to:

- Minimizing the number of PGMs
    - Choose PGMs with large or power-dense prime movers to achieve the power requirement with less prime movers
- Maximize the number of PGMs
    - Choose many smaller PGMs that may incorporate energy storage modules (ESM) such as fuel cells to achieve the power requirement in an effort to maximize energy generation redundancy
- Minimize the total weight of all PGMs
    - Optimize various combinations of PGMs to reduce the overall weight of the IPS architecture to achieve the power requirement
- Minimize the total volume of all PGMs
    - Optimize the overall compartment size as result of selecting PGMs to achieve the power requirement with minimum volume
- Minimize fuel consumption

- Choose PGMs to achieve the power requirement with minimal fuel consumption
- Reduce variability
  - Choose a common set of PGMs in an effort to reduce spare parts and specialized operational and maintenance training

The maximum number of PGM selections to meet a particular power requirement should be restricted to minimum manageable number. The recommended maximum number based on machinery plants of modern conventionally powered naval ships and various IPS architecture proposals is between four to six (N. H. Doerry, 2005). IPSDMv1.0 allows for a maximum of ten PGMs to allow for inclusion of ESMs.

The designer must also keep in mind the efficiencies of prime movers, generators, cabling, and distribution when selecting PGMs. These efficiencies reduce the electrical conversion effectiveness of the prime mover within the PGM, and must be accounted for to reflect the actual power delivered to propulsion and ship service electric loads. Therefore, selections should be made based on the maximum output of the PGM at the power connection source and not on maximum power delivered by any prime mover within the PGM. The power connection source is assumed to originate from a switchboard or specially designed PCM as shown in Figure 3-1.

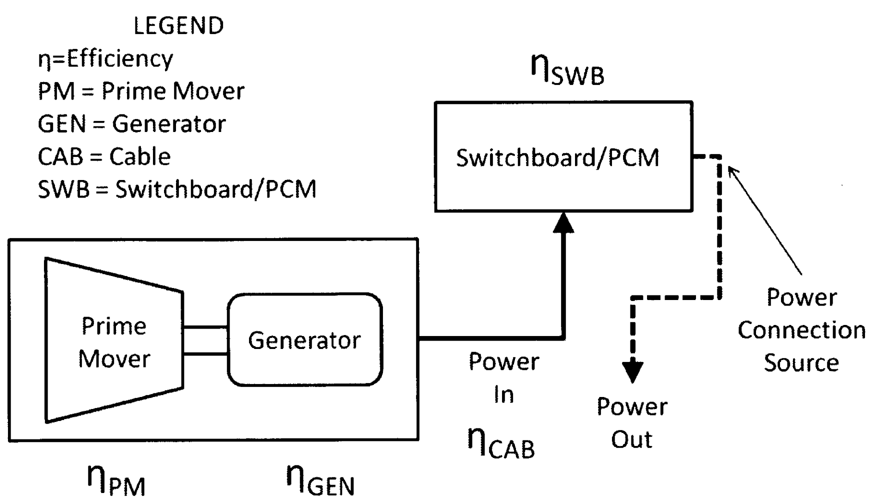


Figure 3-1: PGM Efficiency Pictorial

This power connection source also has an output voltage (e.g. 4.16 kVAC, 13.8 kVAC, etc.) and frequency (e.g. 60 Hz, 400 Hz, etc.) that may require additional equipment to invert or convert it further in the IPS architecture.

In addition to selecting the suitable number of PGMs in naval ship design, the designer must account for redundant power generation. The US Navy specifies that all naval ship designs shall maintain enough ship service electrical capacity should one generator be taken offline. This instruction is informally known as the "N+1 criterion."

The designation between ship service electrical and propulsion loads becomes blurred for a ship with IPS; however, it is important to make an initial designation when selecting PGMs early in the design process in order to satisfy the N+1 criterion. Doing so will aid the designer in future design iterations to make system-level tradeoffs by selecting discrete PGMs for various powering profiles such as reducing propulsion power to increase ship service electrical capacity for a particular mission.

In summary, it is important for the designer to develop a PGM selection design philosophy at the start of the process when selecting PGMs to fulfill the power generation requirement. The philosophy will influence decisions further in the ship design process, and the PGM selections may become a constraint that carries through the entire design cycle. Lastly, the designer must be aware of design standards such as the N+1 criterion that may influence PGM selections and its impact to eventual arrangement of the IPS architecture.

3.2.2. PROPULSION MOTOR MODULE SELECTION

The PMM selection philosophy can be based on either 1) the required propulsion power value from the power requirement (see Section 3.1.1), or 2) initially estimating the propulsion power requirement by assigning a propulsion percentage factor (PPF) to the total power requirement. A PPF allows the designer to assign a percentage of the total power requirement to propulsion only with the remainder allocated to ship service electrical demand.

For the initial design cycle, without a hull form selected or known propulsion power requirement, it is recommended that a PPF factor be applied to the total power requirement. This assumption should be applied to new-concept designs at the start of the design cycle, and may change as the ship design increases in fidelity in additional cycles. Since IPS is assumed to be a fully integrated system, power from other PGMs not intended for propulsion loads at certain power profiles may be partially drawn into the propulsion system. Applying a PPF to the total power requirement initially allocates a defined power level for propulsion for a desired maximum speed as a percentage of the sum of PGM outputs. Therefore, when a hull form geometry is eventually selected, hull resistance estimates at a particular speed can be compared to the allocated propulsion power level, allowing the designer to tradeoff speed and power early in the design process. The remaining power is assumed to be used for ship service electrical loads.

Once a propulsion power requirement is established, PMM modules are selected in order to meet the desired propulsion power requirement. A disadvantage of electric propulsion is the transmission efficiency. Overall efficiencies of electric propulsion drivetrains are much less than traditional mechanical propulsion drivetrains. Figure 3-2 depicts the average differences in efficiencies.

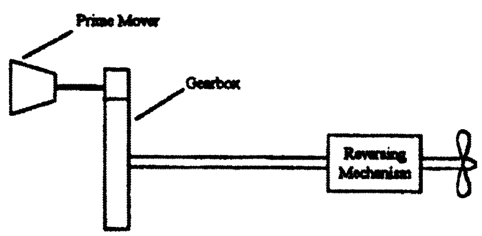


Fig 1 Mechanical transmission – typical efficiency at full power: fpp – 95%; cpp – 93%

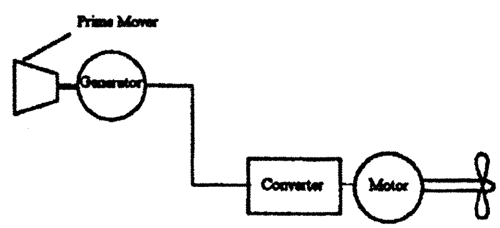
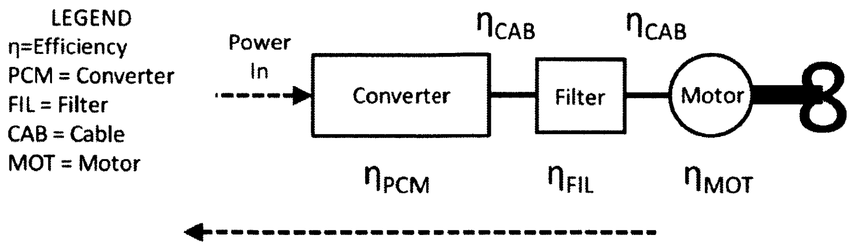


Fig 2 Electrical transmission: typical efficiency at full power with fpp – 89%

Figure 3-2: Mechanical versus Electrical Transmission (Hodge & Mattick, 1995)

As a result, electric drivetrains require greater power input than the maximum rated motor shaft power. As depicted in Figure 3-2, efficiencies for electric propulsion are on the order of 89% as compared to mechanical propulsion with efficiencies of 93-95%. The discrepancy in transmission efficiency is due to the number of equipment and cabling required for electrical transmission, each with individual efficiencies less than unity. Therefore, for a given PMM, the required input power can be estimated by following the power through the drivetrain from the motor rating to the converter. Figure 3-3 depicts this process.



$$\text{Power}_{\text{IN}} = \frac{MOTOR_{OUT}}{\eta_{MOT}\eta_{CAB}\eta_{FIL}\eta_{CAB}\eta_{PCM}}$$

Figure 3-3: PMM Power Input

The output of this method estimates the required power input to achieve a desired motor output.

Once the PMM selections are made, the sum of the selected PMMs can be computed. The sum of the selected PMMs provides two values to the designer:

1. The propulsion motor power.
2. The total input power required to achieve a desired propulsion power, which should be greater than the sum of power delivered by the propulsion motors.

The total propulsion motor power can then be compared to the propulsion power requirement. Also, the total input power can be subtracted from the total power requirement, and compared the ship service electrical load requirement. This "remainder" power is the source of the initial ship service power constraint, and the net result from further deductions in the IPS design process. The further deductions will yield power available for payloads and unidentified ship service loads.

3.2.3. ADDITIONAL AUXILIARY SYSTEMS

The majority of the auxiliary systems within IPSDM are dependent on PGM and PMM selections, as discussed in Section 2.2.2; however, additional auxiliary systems may be required for compartment and zonal systems. These additional auxiliary systems are not accounted for within PGMs and PMMs, but are comprised of equipment for distributed systems that interface with the machinery compartments. Two additional auxiliary systems within IPSDM are identified to be sea water cooling and firemain systems because they are assumed to interface with the hull in the machinery compartments. The placement of the equipment associated with each sea water cooling and firemain system will influence the location of other equipment within the compartment, especially for access and removal. The sea water cooling system is presumed to be a network of piping connecting hull mounted pumps to various installed heat exchangers throughout the ship. The firemain system is presumed to be a network of piping and pumps distributed throughout the ship to provide water in the event of a fire.

Although IPSDM does not design the entire cooling and firemain system, it does allow the designer to allocate space and power within the machinery spaces for pumps, strainers, sea chests and related equipment that will interface with each of the distributed systems. It is important that the designer understand the relationship between the equipment and its role within the ship to effectively integrate their functions into a unified system. Pieces within IPSDM may help better integrate and locate the distributed systems. Other specialized design tools such as MIT's *Cooling System Design Tool (CSDT)*, can take advantage of equipment locations as design inputs to design the distributed cooling system (Fiedel, 2011).

3.3. ELECTRICAL LOAD ANALYSIS

Once the PGM, PMM, and additional auxiliary system selections have been satisfied, an electrical load analysis of the IPS auxiliary equipment can be conducted. The electrical load analysis is conducted on all equipment within IPS that require electrical power to perform a function such as the fuel service systems, lube oil systems, and start air systems.

In order to perform the electrical load analysis, the electrical load of the equipment must be known or assumed within the equipment database. Within IPSDM, this value is assumed to be the maximum continuous rating of the equipment. Using the maximum continuous rating of the equipment allows MIL-STD-2189(SH) Section 310-1 (DDS 310-1), *Electrical System Load and Power Analysis for Surface Ships*, to be utilized in estimating the total electrical load of the auxiliaries. Utilizing DDS 310-1 allows IPSDM to better estimate the auxiliary electrical loads under standardized naval guidance. The scope of DDS 310-1 is defined as follows (NAVSEA, 1990):

> *This standard provides procedures for preparing an electrical system load and power analysis for conventional-powered surface ships. However, this standard may be used as a basis for preparing a load and power analysis for a ship powered by other means.*

Within DDS 310-1, five ship electrical load operating conditions are also identified. The five operating conditions are defined as follows (NAVSEA, 1990):

- *Anchor: a condition in which the ship supplies all electric power while the ship is at anchor.*
- *Shore: a condition in which the ship receives all electric power from a shore facility or a tender.*
- *Cruising: a condition in which the ship cruises at design cruising speed, without ship ordnance or at general quarters, but with power for test and checkout of combat systems.*
- *Functional: a condition in which the ship is performing its designed function. The following are examples of a functional condition: battle for destroyers and frigates, air operations for aircraft carriers, debarking operations for cargo ships, replenishment-at-sea of ships for combat support or store ships, and tending operations for tenders and repair ships.*
- *Emergency: a condition in which the ship is on emergency generators with ship service generators down. The emergency generators, as a minimum, supply loads associated with the following:*
    - *Surface combatant: emergency ship control and selected weapons.*
    - *Aircraft carrier: emergency ship control and either selected weapons (offensive) or limited air operations (recovery and strike down of aircraft).*
    - *Amphibious: emergency ship control and limited unloading operations.*
    - *Auxiliary: emergency ship control and selected weapons*
    - *Mine warfare and patrol craft: emergency ship control.*
    - *Service craft: these craft are only required to supply navigation lights and communication during emergency conditions.*

With all five conditions included into IPSDM, DDS 310-1 is applied to each auxiliary equipment instance in the following manner (NAVSEA, 1990):

> *In preparing system load and power analyses, operating load factors are assigned for each individual item of equipment for each condition of operation. The multiplication of these factors by the connected load (rated kilowatt (kW) input) for each item of equipment gives the demand load of that item for each condition of operation.*

DDS 310-1 provides the typical operating load factors as a guide in determining a relationship between the total connected load and the actual operational load. Table 3-1 shows an example of the typical operating load factors for surface ships as applied to IPSDM.

Auxiliary Equipment	ANCHOR	SHORE	CRUISING	FUNCTIONAL	EMERGENCY
GENERATOR_LUBE_SYSTEM	0.2	0.2	0.5	0.7	0.4
ENGINE_FUEL_SYSTEM	0.4	0.1	0.9	0.9	0.0
START_AIR_SYSTEM	0.4	0.4	0.2	0.2	0.0
SEA_WATER_COOLING_SYSTEM	0.7	0.5	0.7	0.7	0.4
ENGINE_LUBE_SYSTEM	0.2	0.0	0.9	0.9	0.0
PMM_MOTOR_LUBE_SYSTEM	0.0	0.0	0.9	0.9	0.0
PMM_POWER_FILTER	0.0	0.0	0.9	0.9	0.0
FIRE_SYSTEM	0.2	0.2	0.2	0.4	0.4

Table 3-1: DDS 310-1 Operational Loading Factors for Surface Ships (NAVSEA, 1990)

The output of this process yields the total electrical load of each compartment, and the sum of the compartments yields the total electrical load of the selected equipment for IPS. The sum of the electrical load is then applied to the total power left available for ship service electrical load after supplying maximum power to the propulsion electrical load. Applying the electrical load to the ship service power available effectively reduces the actual ship service power available and provides an estimate for net power available. The new power available is the ship service electrical power available for the remainder of the ship after achieving the desired propulsion electrical power load. Applying this method is useful in determining the overall IPS auxiliary equipment electrical load under assumed operating conditions.

3.4. ZONAL ELECTRICAL DISTRIBUTION SELECTION

Electrical distribution is key to implementing IPS. Without the electrical distribution system, power management for propulsion and ship service electrical loads could not be integrated. IPSDM allows the designer to select the desired architecture and tailor it to the equipment selections made earlier in the IPSDM design process. It also allows the designer to define electrical zones based on the number of machinery compartments as a basis. The zonal definition can be expanded after defining mission systems and ship geometry, but minimally IPSDM starts the zonal definition process.

The following five items of information generated within IPSDM are presumed to be sufficient in aiding in the determination of the number of electrical zones the ship may require. The basis for defining the electrical zones within IPSDM at the earliest stages of design are:

1. Number and type of machinery compartments are known.
    a. Can estimate the number of electrical zones based on this information.
2. Power information from equipment selections is available.
    a. Once the designer has satisfied the power requirement within IPSDM, power generation, propulsion, and additional auxiliary equipment sources and demands are defined.
3. Total distributable power is known, based on equipment selections.
    a. Can define power in each zone as a percentage of total available ship service power available based on the number of defined zones.
4. Estimation of ship service electrical power is known after defining propulsion electrical loads.
    a. Can divide the ship service electrical power into buses (i.e. port and starboard).
5. Auxiliary equipment loads and locations are known after applying DDS 310-1.
    a. Can determine net power available in each zone by subtracting known auxiliary demand after defining the power in each zone as a percentage of total available ship service power.

While determining zonal definition of the ship, choices in AC or DC voltage distribution can be assessed and selected. Section 1.2.2.2 describes several naval IPS architectures each with benefits and drawbacks depending on the selection of power generation and propulsion equipment. The specific modules to support the desired voltage for distribution are identified in Section 2.2.2.3. The voltage and number of zones determination plays a role in determining the number and types of distribution equipment required. Each zone may require multiple rectifiers, converters, and inverters to satisfy the zonal power requirements. The number and location of this equipment must be accounted for in determination in the overall machinery arrangement and service highways.

3.5. THERMAL LOAD ESTIMATION

Coupled with the rise of ship board power requirements depicted in Figure 1-2, thermal loads are also becoming increasing critical to the design of naval ships and should not be overlooked.

Figure 3-4 depicts the thermal trend for mission systems as a function of 200 Ton Chiller Plants (Backlund, 2010).

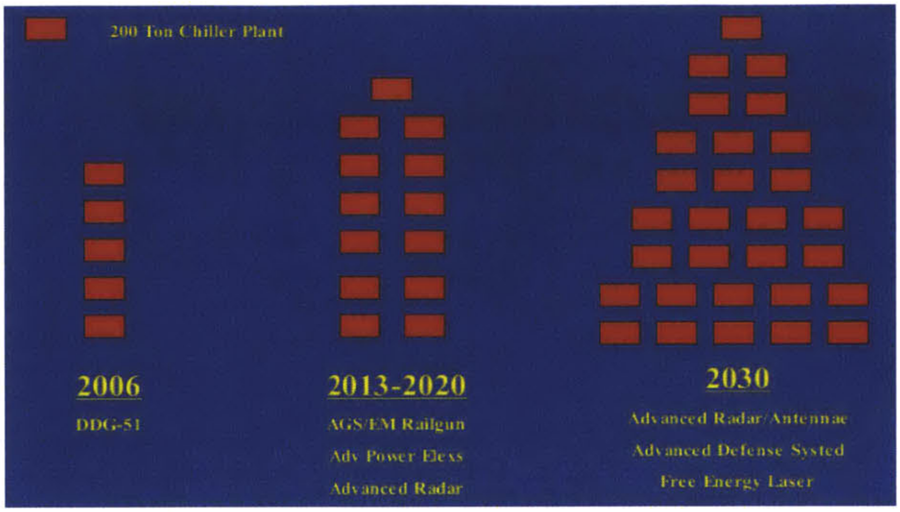


Figure 3-4: Electric Ship Thermal Load Projections (Backlund, 2010)

The thermal trend is also exacerbated by the use of IPS. IPS requires more power electronics to distribute and condition power, requiring some form of thermal management. The thermal load of the equipment can be either known or computed based on equipment efficiency and maximum continuous electrical load. With the power generation, propulsion, auxiliary, and distribution equipment selected, IPSDM performs a thermal load estimation.

In an effort to estimate the thermal loads of the IPS architecture, DDS 310-1 was applied in conjunction with assumed equipment efficiencies. The following assumptions are applied to the IPS thermal load analysis:

1. Ambient temperature assumed constant.
    a. The environment exterior to the ship can influence the interior temperature (e.g. a 100 degree Fahrenheit day or a 32 degree Fahrenheit day). The ambient temperature is assumed to be constant at an ideal temperature (e.g. 72 degrees Fahrenheit).
2. Thermal load is estimated as energy loss due to inefficiency of equipment (e.g. equipment maintains 95% efficiency with 5% in thermal losses)
    a. Other losses in the system are present such as acoustical, but are assumed small.
    b. Assumed all losses as heat.

3. Assumed thermal load generated by equipment to be synonymous with electrical load of equipment.
    a. The same loading factors per DDS 310-1 were applied to equipment for the thermal loading analysis. Applying DDS 310-1 introduces an operational standard profile to the thermal loads of the system. Section 3.3 discusses DDS 310-1 in further detail.

The output of this process yields the total thermal load of each compartment, each electrical zone, and the sum of the compartments yields the total thermal load of the selected equipment for IPS; however, the thermal load estimation process does not identify the cooling mediums or the design of a thermal management system. Other specialized design tools such as CSDT, can take advantage of thermal load analysis output for the construction of a thermal management system in conjunction with the mission system thermal load.

3.6. MACHINERY ARRANGEMENT

Once all of the equipment selections have been satisfied, the final step in IPSDM is to arrange the equipment. The arrangement of equipment is the largest portion of the IPS design process, and is the most time intensive portion, especially during a clean-sheet design. This section highlights important guidelines and philosophies collected from historical design data sheets, discussions with experts in the field, and texts on the subject of marine engineering for use within IPSDM.

3.6.1. EQUIPMENT ARRANGEMENT PHILOSOPHY

Arranging equipment in a compartment is similar to constructing a three-dimensional puzzle. Pieces must be in located specific areas of the ship in order to maximize operational efficiency and ship recoverability while minimizing total volume. Spacing and positing equipment for manned access is critical for maintenance, construction, and operation. It is the driver behind the arrangement of equipment within a space. The following list forms the basis of the machinery arrangement philosophy and is largely derived from *Design of Propulsion and Electric Power Generation Systems* (Woud & Stapersma, 2008). Guidelines within the list relating to IPS are expanded.

- A mechanical drive propulsion plant is located such that it can be connected to the propulsors.

    - For an IPS ship, this recommendation applies to the propulsion motor and its support equipment. The position of the propulsion motor can influence the overall beam of the ship and the propeller diameter, if multiple propeller shafts are required in the design.
- Auxiliary equipment is located in the direct vicinity of the main equipment it supports.
    - Locating the auxiliary in direct vicinity of main equipment reduces piping, cabling, and vulnerability.
- Various equipment should be located low within the machinery spaces.
    - Fuel service, lube oil service, fire main pumps, and sea water cooling pumps should be located low in the spaces to minimize piping and head losses.
- Various equipment needs to be located high within the machinery spaces.
    - For an IPS ship, it is recommended that all electronic equipment (i.e. PCMs, power filters, etc.) be located as high as possible in the machinery compartment. Locating the electronic equipment higher in the machinery compartment avoids failure should a space flood or another liquid interfacing equipment (e.g. sea water cooling pump, lube oil pump, etc.) located above the electronic equipment leak.
- Various equipment do not have strict location requirements within the machinery spaces.
    - An example includes the start air system. However, auxiliary equipment considerations in this category should be made so long as the equipment is in vicinity the main equipment it supports.
- Sufficient access space should be provided for control, monitoring, and maintenance of machinery and electrical equipment.
    - Typical widths for passageways within the machinery spaces are 3-4 feet for access (Department of the Navy, 1996).
- Prime movers should be located facing fore or aft, not athwartships.
    - Locating the prime movers fore and aft avoids prime mover performance issues as the ship rolls.

3.6.2. IPSDM ARRANGEMENT PROCEDURE

The IPSDM arrangement process is divided into three steps: equipment definition, compartment definition, and stack-up definition. The process is illustrated in Figure 3-5.

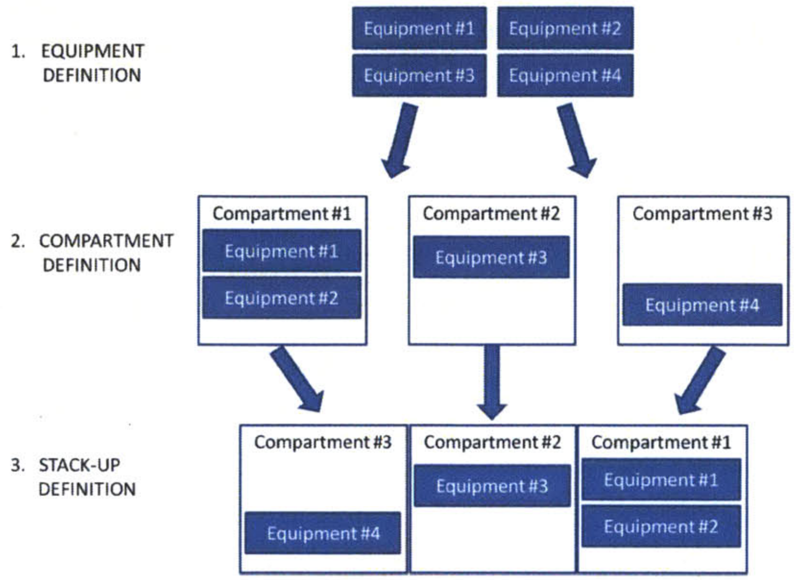


Figure 3-5: IPSDM Machinery Arrangement Process

The process outlined in this section is iterative and begins at the equipment level. The equipment definition is defined by the equipment selections made earlier in the IPSDM process. The second level is based the division of equipment into specified compartments. The overall dimensions of the compartments are determined individually based on the number and dimension of equipment in the compartment. The third level combines the compartments into a single machinery block, defining the machinery bulkheads for the ship. Within IPSDM, the designer can adjust the sequence of compartments within the stack-up configuration. OMRs, if required by the IPS design, are not included in the stack-up definition because they are viewed as separate payloads in ESSDT (Thurkins, 2012).

In order to use the IPSDM machinery arrangement process effectively, the following additional machinery arrangement guidelines are as follows.

1. Locate the prime movers, generators, and propulsion motors first within a compartment.
    a. Locating the largest items in the machinery plant first places an arrangement constraint on the auxiliary items. The location of the auxiliary items revolves around the location and position of major equipment.

b. Prime movers

  i. Position the non-power generation end (i.e. the end not connected to a generator) of the prime mover in close proximity to a compartment bulkhead to minimize ducting impacts to the spaces above the machinery space. Should another prime move be located in an adjacent compartment, align that prime mover and the prime mover in the adjacent space with a common bulkhead to minimize ducting impacts to the spaces above the machinery space. See Figure 3-6 for visualization.

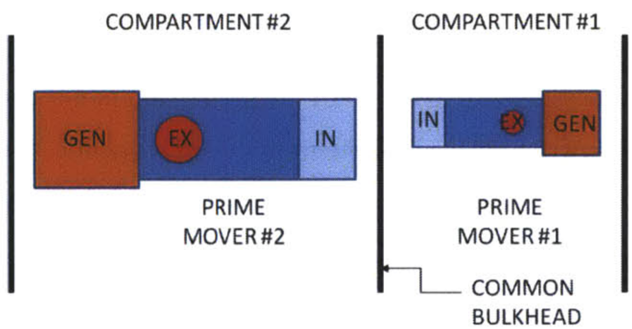


Figure 3-6: Common Bulkhead Illustration

  ii. If possible, locate the prime mover low in the machinery compartment to keep the center of gravity of the machinery plant to a minimum.

c. Generators

  i. Assume large generators as life-of-ship parts, unless otherwise known. This assumption reduces required space forward of the generator for maintenance.

d. Propulsion motors

  i. The arrangement of the propulsion motors directly affects the propeller diameter estimation for a monohull ship. Placing two propulsion motors on opposite sides (i.e. port and starboard) from the centerline of the ship at a set distance, provides IPSDM an estimate on propeller diameter. The diameter is a function of the PMM offset distance within IPSDM.

ii. When arranging propulsion motors, be aware of the shaft depression angle. See Figure 3-7 for visualization.

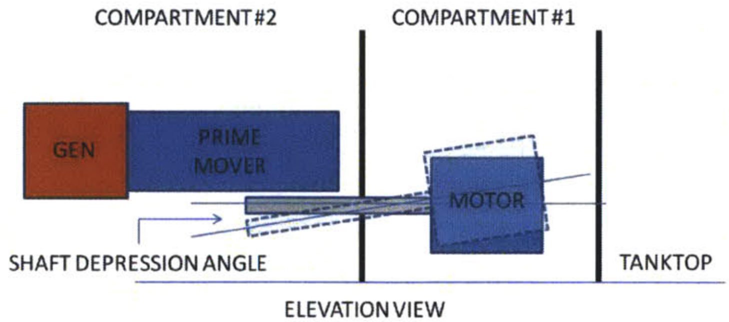


Figure 3-7: Shaft Depression Illustration

iii. Understand the position of the propulsion motor and machinery compartment(s) aft of the motor compartment as it may affect the height and position of the equipment in the aft compartment(s) in the stack-up configuration. See Figure 3-7.

iv. Locate the propulsion motor low in the machinery compartment to account for propeller diameter sizing and to keep the center of gravity of the machinery plant to a minimum.

v. Assume life-of-ship part, unless otherwise known.

2. Cluster stacks when possible.
   a. If two or more prime movers occupy adjacent spaces, as shown in Figure 3-8, route and cluster the exhaust stacks above one of the spaces.
   b. For gas turbine driven ships, it is critical to minimize elbows of the intake trunk to reduce head losses.

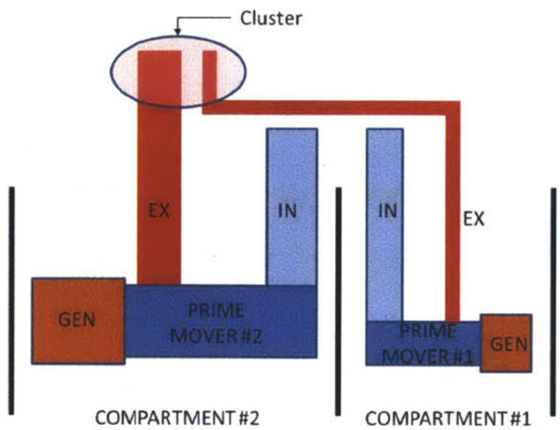


Figure 3-8: Stacks Illustration

3. Envision the cabling required to connect electronic equipment and the distribution buses together.
    a. Locating equipment (i.e. PCM-1) in vicinity to service highways and generators (i.e. PCM-4) can reduce cable length within an electrical zone.
    b. Clustering electronic equipment within a machinery space can also reduce required deck area.
4. Compact the machinery arrangement as much as possible.
    a. Account for curvature of hull in arrangement to minimize beam and depth of the ship.

All aspects of equipment arrangement must be understood in order to effectively utilize IPSDM at the earliest stage of ship design.

3.6.3. ADDITIONAL COMPARTMENT ACCOUNTING

The PGM and PMM selection process in Section 3.2 requires the designer to designate the location and type of compartment the equipment will be located; however, the design may require additional spaces that may not contain PGM or PMM equipment. These "null" compartments may play a role in the overall survivability assessment of the ship later in the ship design process. The additional compartment is intended to provide sufficient space in the event of damage between machinery compartments, and in some cases must be included to separate two or more vital power generation and propulsion spaces. An example of an additional compartment is as shown in Figure 3-9.

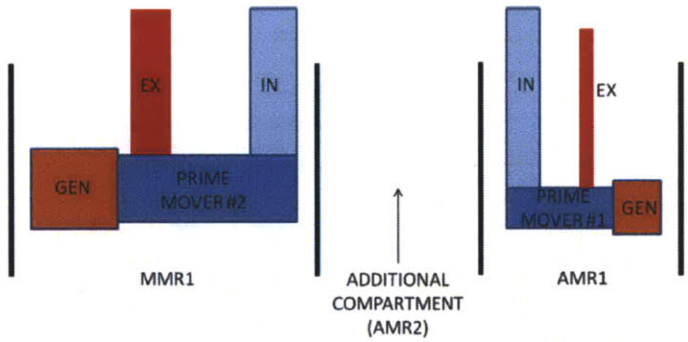


Figure 3-9: Illustration of Additional Compartment

However, the additional compartments can be used to allocate equipment not included in the database during future ship design iterations such as heat exchangers, or allocate equipment within the equipment database for power distribution such as PCM-1s and PCM-2s.

Lastly, the determination of the dimensions of the additional compartment is defined by the designer, and may not be based on equipment. The length of the additional compartment can be determined using naval standards or assessments from a floodable length analysis. Determining the overall dimensions of this compartment can be an iterative process requiring data further in the total ship design process to establish the additional compartment length. The length of this compartment can play a vital role when assessing the survivability of the ship.

3.6.4. NUMBER OF DECKS AND DECK HEIGHTS

The number of decks and deck heights are entered manually within IPSDM. The purpose is to provide the designer the flexibility of specifying uniform spacing, or define deck heights based on equipment height. Using equipment size as determination should be used when applicable. For example if a particular switchgear is 15 feet in height, defining a deck height of 15 feet may not be useful within the design; however if a piece of equipment is 8 feet in height, perhaps adding one to two feet in deck spacing may be a useful within the design. It is also recommended that 3-4 feet of height be allocated above the machinery compartment tank-top for maintenance and construction access. See Figure 3-10 for illustration.

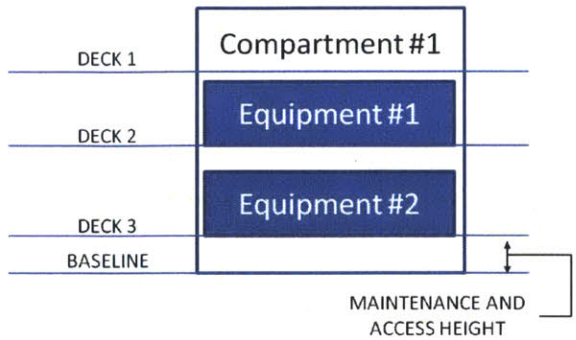


Figure 3-10: Maintenance and Access Deck Height Illustration

Ultimately, the number of decks and their heights aid in defining the overall depth of the ship.

3.7. WEIGHT ESTIMATION

The weight of the equipment is known within the equipment databases. As a result the weight estimation procedure within IPSDM simply sums the weight of the equipment, and divides the weights into separate accounting weight groups, a standard provided by the US Navy's Expanded Ship Work Breakdown Structure (ESWBS) (*Marine Vehicle Weight Engineering*, 2007). The division of weight into each ESWBS section is automated via an algorithm within IPSDM based upon the category of the equipment (e.g. fuel service, distribution, propulsion, etc.). The IPSDM procedure estimates weight groups 200 (Propulsion), 300 (Electrical), and 500 (Auxiliary).

Additional weights within the three groups are not estimated because they require the total ship design for estimation. The weights not estimated are as follows:

1. Intake and exhaust ducting
    a. The maximum extent of both intake and exhaust ducting is unknown until the IPS architecture is placed into a ship hull with a deckhouse attached.
2. Propeller shafts
    a. The length of the propeller shaft(s) is unknown until the hull form and its length is defined.
3. Propellers
    a. A diameter is estimated in IPSDM, but is subject to change based on hull form geometry at the stern.
4. Cabling

a. Service highways can be identified in IPSDM, but the extent of those highways is limited to the machinery compartments.

Also not estimated in IPSDM are weight groups 100 (Hull Structure), 400 (Command and Surveillance), 600 (Outfit and Furnishings), and 700 (Armament). The purpose of not estimating these weights is to allow other specialized programs to estimate the weight at a later stage of the design process. These weight groups are also estimated and refined in tools like ESSDT and CSDT. Ideally, when the baseline design of the total ship is complete, all weights relevant to the design will be accounted for.

3.8. OUTPUT

Once all power requirements, equipment selections, and arrangements are satisfied, the data associated with the developed IPS design through the IPSDM process is stored into a database. The IPSDM information stored within the database is as follows:

- Total installed brake power
    - Sum of all installed prime movers power output
- Total distributable power
    - Sum of all power emanating from the switchboards with one PGM offline
- Total required propulsion power
    - Sum of power required to enter the PMM
- Total shaft power
    - Sum of shaft power emanating from the PMM
- Net power available
    - Sum of available power for ship service loads after subtraction of machinery auxiliary power demand
- Total auxiliary power at maximum demand
    - Sum of power required to operate auxiliary support systems for PGMs and PMMs
- Thermal load
    - Sum of estimated cooling required for all equipment
- Margins and allowances
- All compartment names, associated overall dimensions (length, width, and height), and volumetric centroids about the origin (0,0,0).

- The machinery stack-up transverse bulkheads longitudinal location
- Number of decks and their respective heights
- Propeller diameter, type (assumed fixed pitch for IPS), and associated maximum motor RPM
- The entire list of selected equipment each with:
    - Overall dimensions (length, width, and height)
    - Equipment volumetric centroid (relative to each compartment's centroid)
    - Weight
    - Location (identifies compartment)
    - ESWBS classification
- Exhaust and intake diameters and location

These outputs act as inputs into ESSDT. ESSDT executes the remainder of the ship design spiral by integrating IPS, mission systems, hull form, and deckhouse for further analysis in GRC Paramarine (Thurkins, 2012). Values that directly affect ESSDT are:

- Compartment dimensions
- Equipment locations
- Equipment weight
- Propulsion and ship service power levels

Other tools such as CSDT are used to increase the fidelity of the design, at each instance obtaining more information as the ship design progresses. Ideally, the IPSDM database is populated with multiple IPS designs, providing the ESSDT user options in various arrangement and power levels to achieve a balanced ship design.

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4. CASE STUDY

The intention of the case study was to demonstrate the application of the IPSDM process and the ability to perform system-level tradeoffs independent of hull geometry. The purpose of this exercise was to generate two IPS machinery plants as input into ESSDT for a clean-sheet medium-size surface combatant design. The motivation for each IPS design was to provide the same capability in power as a modern US Navy Destroyer with IPS. Variant 1 comprised of seven PGMs, while Variant 2 focused on minimizing the number of PGMs of Variant 1 while maintaining an equivalent energy capability. The "smaller" plant, Variant 2, was then compared to Variant 1 to quantify the space, weight, and thermal impacts between each equally capable IPS design.

4.1. CASE STUDY ASSUMPTIONS

Before performing the design exercise, several assumptions were made in order to maintain a measure of commonality between design variants. The overall assumptions of both design variants are as follows:

- Both variants utilized gas turbine PGMs for power generation.
- Both variants designated one ship service PGM offline to satisfy the N+1 criterion. See Section 3.2.1 for further information on the N+1 criterion.
- Deck height between both IPS variants remained constant.
- Assumed Hybrid AC-DC zonal distribution system.
    - Both variants assume AC distribution for propulsion, DC distribution for ship electrical service.
    - Both variants contain Port and Starboard buses.
        - A cable efficiency of 98% was assumed when estimating power transmission between equipment for both variants.
    - Both variants were kept to four zones total.
- The following target power requirement was assumed:
    - The margins and allowances for the power requirement were assumed to be zero. The margins and allowances were presumed to be already incorporated into the estimated propulsion and ship service electrical loads for a modern US Navy Destroyer.

- Electrical demand of 75-84 MW for propulsion
    - 75 MW was the estimated power required for modern US Navy Destroyers (i.e. DDG-51 Flight I) to achieve a maximum speed of 30 knots ("USS Arleigh Burke (DDG-51)," 2012). Variant 2 focused on this number because its design objective was to reduce the overall size of the ship (i.e. beam, length, displacement), allowing the ship to maintain the speed requirement with less power.
    - 84 MW was estimated based on later flights of the Arleigh Burke Class Destroyers for installed propulsion power ("Arleigh Burke Class Destroyer," 2012). Variant 1 focused on this number because its design was perceived to require more power due to the inefficiencies of the electric propulsion drivetrain, and would result in a higher displacement to achieve a maximum speed of 30 knots. See Section 3.2.2 for more information on the inefficiencies of the electric propulsion drivetrain.
- Electrical demand of 7 MW for ship service electrical loads
    - 7 MW was the estimated ship service electrical load with two Rolls-Royce Allison 501K generator sets online (Rolls-Royce, n.d.). The ship service electrical load value was assumed to be the vital load at maximum propulsion power.

The assumptions and operations inherent at each individual stage of the IPSDM process (e.g. electrical load estimation, thermal load estimation, etc.) remained constant and unchanged between design variants. Chapter 3 discusses the operations, assumptions, and methodologies within IPSDM.

4.2. VARIANT 1 RESULTS

The equipment selection for Variant 1 was based on a typical US Navy Destroyer. Table 4-1 lists the equipment PGM and PMM selections.

EQUIPMENT TYPE	ITEM	ONLINE (YES/NO)
1, PGM, GT	LM2500_PLUS	YES
2, PGM, GT	LM2500_PLUS	YES
3, PGM, GT	LM2500_PLUS	YES
4, PGM, GT	LM2500_PLUS	YES
5, PGM, GT	501_K34	YES
6, PGM, GT	501_K34	YES
7, PGM, GT	501_K34	NO
1, PMM	AIM_42MW	YES
2, PMM	AIM_42MW	YES

Table 4-1: Variant 1 PGM and PMM Equipment List

Table 4-1 also identifies which PGM was assumed online to satisfy the power requirement with one PGM offline. The General Electric (GE) LM2500-Plus gas turbine was chosen over the standard GE LM2500 installed in the typical Arleigh Burke Class Destroyer after performing several iterations within IPSDM ("Arleigh Burke Class Destroyer," 2012). The GE LM2500-Plus generator set was assumed to deliver approximately 25-30 MW (General Electric, 2006). The GE LM2500-Plus was required to satisfy the power requirement coupled with the need to supply power to an Advanced Induction Motor (AIM) with an assumed shaft power output of 42 MW. The 501-K34 is the standard ship service electrical generator installed in the Arleigh Burke Class Destroyer, and was chosen for this design variant (Rolls-Royce, n.d.). The 501-K34 generator set was assumed to deliver approximately 3 MW.

After selecting the equipment and utilizing the IPSDM process, the arrangement in Figure 4-1 was generated. The arrangement includes four decks with the top three at an average deck height of 9.5 feet. The full list of equipment (i.e. auxiliaries and distribution) depicted in Figure 4-1 is provided in Appendix B.

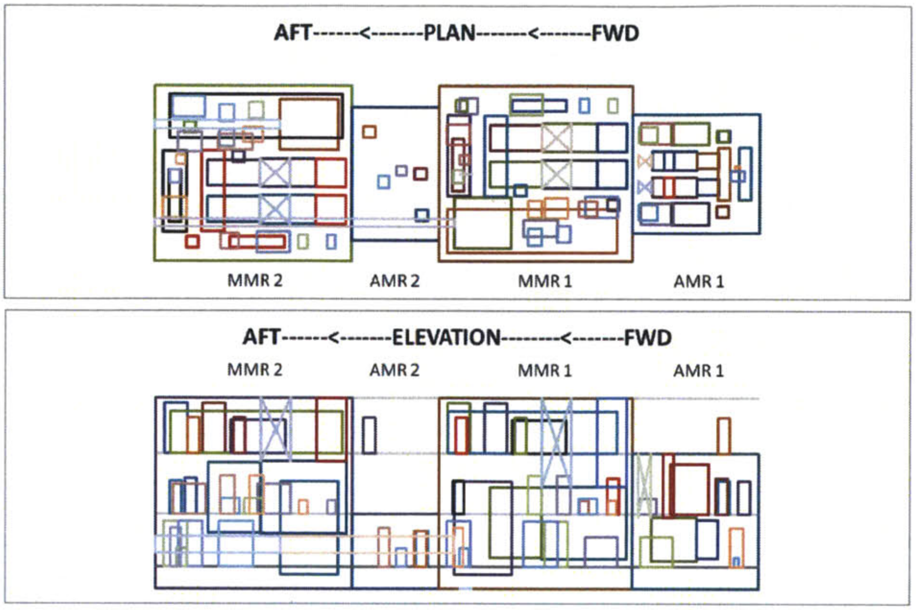

Figure 4-1: Variant 1 Stack-up Arrangement Result

The arrangement philosophy behind Figure 4-1 was to minimize the number and the length of compartments by placing two GE LM2500-Plus generator sets and one PMM into the same compartment. This philosophy was conducted at the cost of increasing the overall width of the compartment. AMR2 was added to increase the survivability of the system through separation. Not pictured in Figure 4-1 is an OMR containing the third 501-K34 generator set. Table 4-2 lists the final characteristics of Variant 1.

CHARACTERISTICS	VARIANT 1
Length (FT)	248.4
Width (FT)	63.3
Weight (LT)	1563.2
Required Cooling (MW)	9.3
Total Installed Brake Power (MW)	108.5
Total Distributable Power (MW)	98.9
Total Required Propulsion Power (MW)	90.0
Total Shaft Power (MW)	84.0
Net Power Available (MW)	7.9
Total Auxiliary Power Demand (MW)	1.0

Table 4-2: Principal Characteristics of Variant 1

The length in Table 4-2 is a combination of the stack-up length of Figure 4-1 and the additional OMR machinery compartment. The propulsion and ship service electrical power requirement was met and exceeded. Variant 1 was divided into four zones, and ship service electrical power was equally divided between each of the zones. Zone_1 includes AMR1 and the forward portion of the ship up to and including the bow. Zone_2 only includes MMR1 while Zone_3 included both AMR2 and MMR2. Combining AMR2 and MMR2 into one zone was performed in an effort to keep the design to four zones for comparison against the second variant. In future design iterations, Zone_3 could be divided into two zones with each compartment occupying individual zones. Zone_4 included OMR1 and the stern of the ship. Figure 4-2 depicts a summary of the zonal distribution.

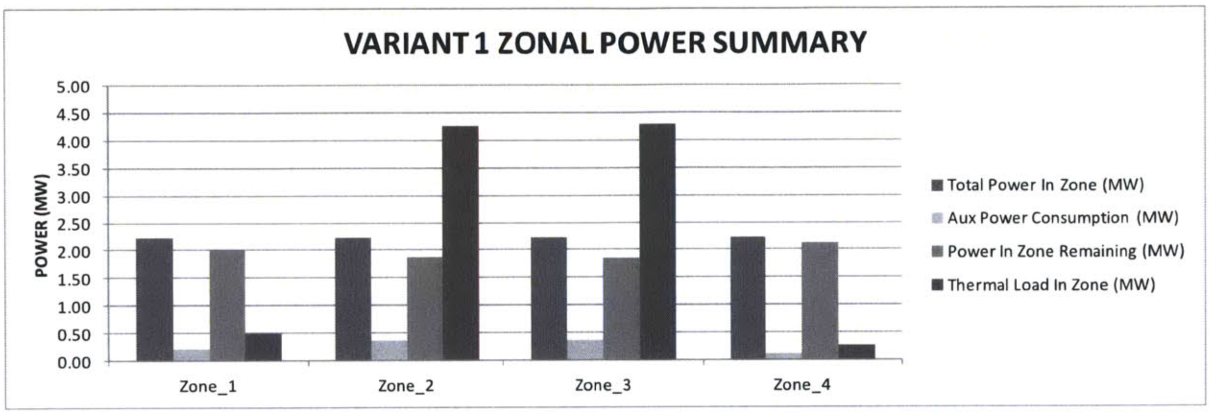

Figure 4-2: Variant 1 IPS Zonal Distribution Summary

The purpose of Figure 4-2 is to illustrate the zonal distribution estimation performed within the IPSDM process. It summarizes the total power in each zone, the auxiliary power demand in each zone, the remaining power in each zone after deducting the auxiliary demand, and the thermal load in each zone. In Figure 4-2, the thermal loads appear to be the largest in Zone_2 and Zone_3 due to the PGMs and PMMs located in those zones. Those zones may require additional thermal management attention later in the ship design process. Once the design satisfies the power requirement and overall design philosophy, the information was then fed into ESSDT for integration with the mission systems and hull geometry.

4.3. VARIANT 2 RESULTS

In an effort to minimize the dimensions of the IPS design in Section 4.2, Variant 2 was developed. The first objective of Variant 2 was to minimize the number of PGMs as compared to the first variant while maintaining an equivalent power generation and distribution capability. The second objective was to minimize the stack-up length by including azimuth podded propulsion in an attempt to mitigate the survivability of the system while increasing the propulsive efficiency of the ship's propulsion system. The arrangement of the propulsion system was envisioned to be contra-rotating system as seen in Figure 4-3.

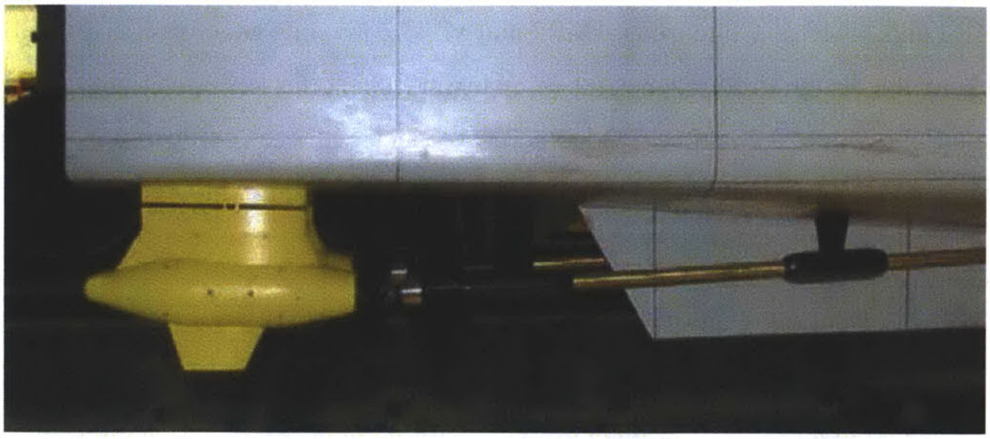

Figure 4-3: Contra-Rotating Arrangement (N. H. Doerry, McCoy, & Martin, 2010)

Based on the objectives above, Table 4-3 lists the PGM and PMM equipment selections and identifies which PGMs were assumed online to satisfy the power requirement with one PGM offline.

EQUIPMENT TYPE	ITEM	ONLINE (YES/NO)
1, PGM, GT	LM6000	YES
2, PGM, GT	LM6000	YES
3, PGM, GT	501_K34	NO
4, PGM, GT	501_K34	YES
1, PMM	AIM_28MW	YES
2, PMM	AIM_28MW	YES
3, PMM	POD_9_8MW	YES
4, PMM	POD_9_8MW	YES

Table 4-3: Variant 2 PGM and PMM Equipment List

The power output of each GE LM6000 generator set was assumed to be approximately 44-47 MW (General Electric, 2006b). The selection of the larger power generation capacity gas turbine allowed for reduction in the number of PGMs in Variant 1 from seven to four in Variant 2 to satisfy all power requirements. Removing three gas turbine generator sets was offset by the addition of two additional azimuth pods and coupled with two 28 MW motors. The reduction in required propulsion power was also offset by the assumed improved propulsive efficiency of the contra-rotating arrangement. Figure 4-4 illustrates the stack-up arrangement for this variant. The arrangement includes four decks with the top three at an average deck height of 9.5 feet.

The full list of equipment (i.e. auxiliaries and distribution) depicted in Figure 4-4 is provided in Appendix B.

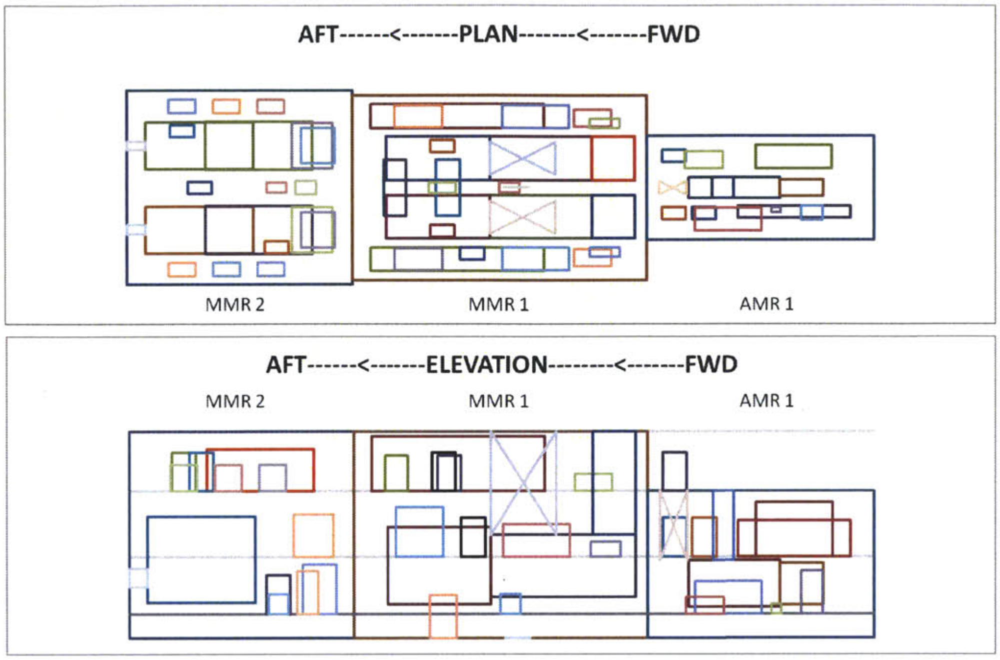

Figure 4-4: Variant 2 Stack-up Arrangement Result

The arrangement philosophy behind Figure 4-4 was to minimize overall dimensions in length and width of the compartment and stack-up. Not pictured is OMR1, containing the second 501-K34 gas turbine, and OMR2, containing both azimuthing pods. OMR1 and OMR2 are assumed to be located aft of midships with OMR2 closest to the transom. Both PMMs are located in MMR2 without the use of a longitudinal bulkhead. Avoiding the use of longitudinal bulkheads reduces the effects of asymmetrical flooding for a given damage scenario. The assumption for not including a longitudinal bulkhead was through the use of azimuthing pods. The azimuthing pods provide a second source of propulsion in the event of damage; therefore, the propulsion motors would not require an additional longitudinal bulkhead or an additional compartment within the stack-up configuration as shown in Figure 4-1. The removal of the additional compartment within the stack-up configuration reduces the overall stack-up length. Table 4-4 presents the final characteristics of reduced-size design.

CHARACTERISTICS	Variant 2
Length (FT)	200
Width (FT)	64.5
Weight (LT)	1188.8
Required Cooling (MW)	8.8
Total Installed Brake Power (MW)	103.7
Total Distributable Power (MW)	94.4
Total Required Propulsion Power (MW)	85.3
Total Shaft Power (MW)	75.6
Net Power Available (MW)	7.4
Total Auxiliary Power Demand (MW)	1.6

Table 4-4: Principal Characteristics of Variant 2

The length in Table 4-4 is a combination of the stack-up length of Figure 4-4 along with OMR1 and OMR2 machinery compartments. The propulsion and ship service electrical power requirement was met and exceeded. Just as in Section 4.2, this IPS variant was divided into four zones, and ship service electrical power was equally divided between each of the zones. Zone_1 includes AMR1 and the forward portion of the ship. Zone_2 includes MMR1 while Zone_3 only includes MMR2. Zone_4 includes OMR1, OMR2, and the stern of the ship, aft of MMR2. Figure 4-5 depicts a summary of the zonal distribution.

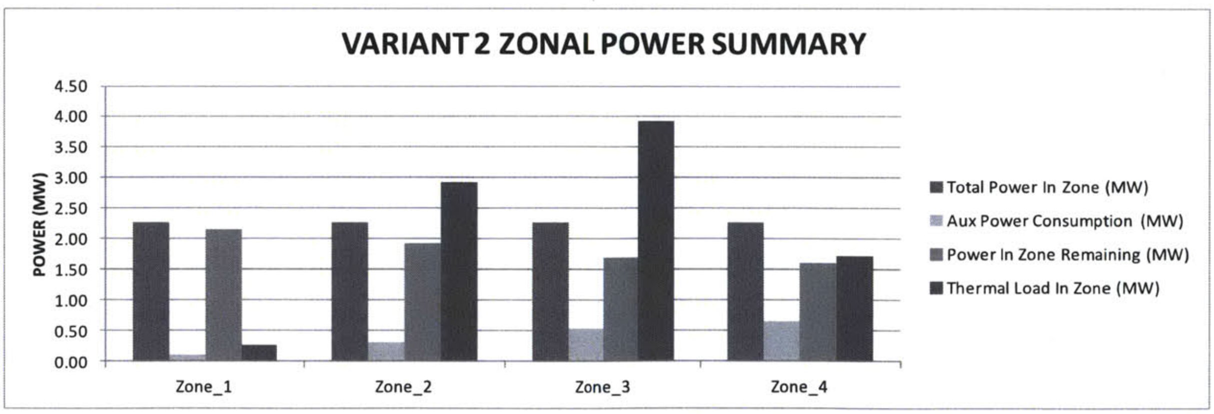

Figure 4-5: Variant 2 IPS Zonal Distribution Summary

In Figure 4-5, the thermal loads appear to be the largest in Zone_2 and Zone_3 due to the GE LM6000 generator sets and the PMMs located in those zones. Zone_4 also shows elevated levels of thermal loading due to the azimuth PMM. Those zones may require additional thermal management attention later in the ship design process. Once the design satisfies the power requirement and overall design philosophy, the information was then fed into ESSDT for integration with the mission systems and hull geometry.

4.4. VARIANT 1 AND 2 COMPARISON

Table 4-5 summarizes the principal characteristics of both variants for comparison.

CHARACTERISTICS	VARIANT 1	VARIANT 2	DIFFERENCE	% DIFFERENCE
Length (FT)	248.4	200.0	-48.4	-19%
Width (FT)	63.3	64.5	1.2	2%
Weight (LT)	1563.2	1188.8	-374.4	-24%
Thermal Load (MW)	9.3	8.8	-0.5	-6%
Total Installed Brake Power (MW)	108.5	103.7	-4.8	-4%
Total Distributable Power (MW)	98.9	94.4	-4.5	-5%
Total Required Propulsion Power (MW)	90.0	85.3	-4.7	-5%
Total Shaft Power (MW)	84.0	75.6	-8.4	-10%
Net Power Available (MW)	7.9	7.4	-0.5	-6%
Total Auxiliary Power Demand (MW)	1.0	1.6	0.6	53%

Table 4-5: Variant 1 and 2 Comparison

Overall both variants vary between an acceptable 4-10% in power capacities. They each maintain equivalent capability in total installed brake power, distributable power, propulsion power, shaft power, and net power. However, total auxiliary power demand increased by 600 kW between variants due to the auxiliary demands associated with the azimuth pods and AIMs.

The overall length between Variant 1 and 2 was reduced by 48 feet while the width difference was 1.2 feet. The width difference is attributed to the use of large gas turbine generator sets and their associated power electronics. The length reduction is attributed to the omission of an additional compartment in the machinery stack-up configuration. Adding azimuth pods allowed for an alternate source of propulsion delivery which did not impede the cumulative reduction in length of the machinery compartments.

The weight of the overall system also was reduced by 20%. Weight reduction was directly attributed to the reduction in PGMs. Reducing the number of PGMs not only decreased the number of prime movers, but the required space, weight, and power of the auxiliary systems to support the prime mover's operation. Also selecting lower power capacity AIMs reduced weight by coupling the smaller AIMs with azimuthing podded propulsors. This propulsion drivetrain allows the designer to arrange and distribute smaller equipment components to multiple locations within the hull (i.e. MMR2 and OMR2).

The overall thermal loads remained equivalent between the two variants. This equivalency is directly attributed to the power distribution and net power available. As a result, since both variants produce equivalent capabilities of power, the thermal loads between the variants remained similar. However, there is a noticeable difference of thermal load distribution within the variants. The comparison of the zonal distribution levels is depicted in Figure 4-6.

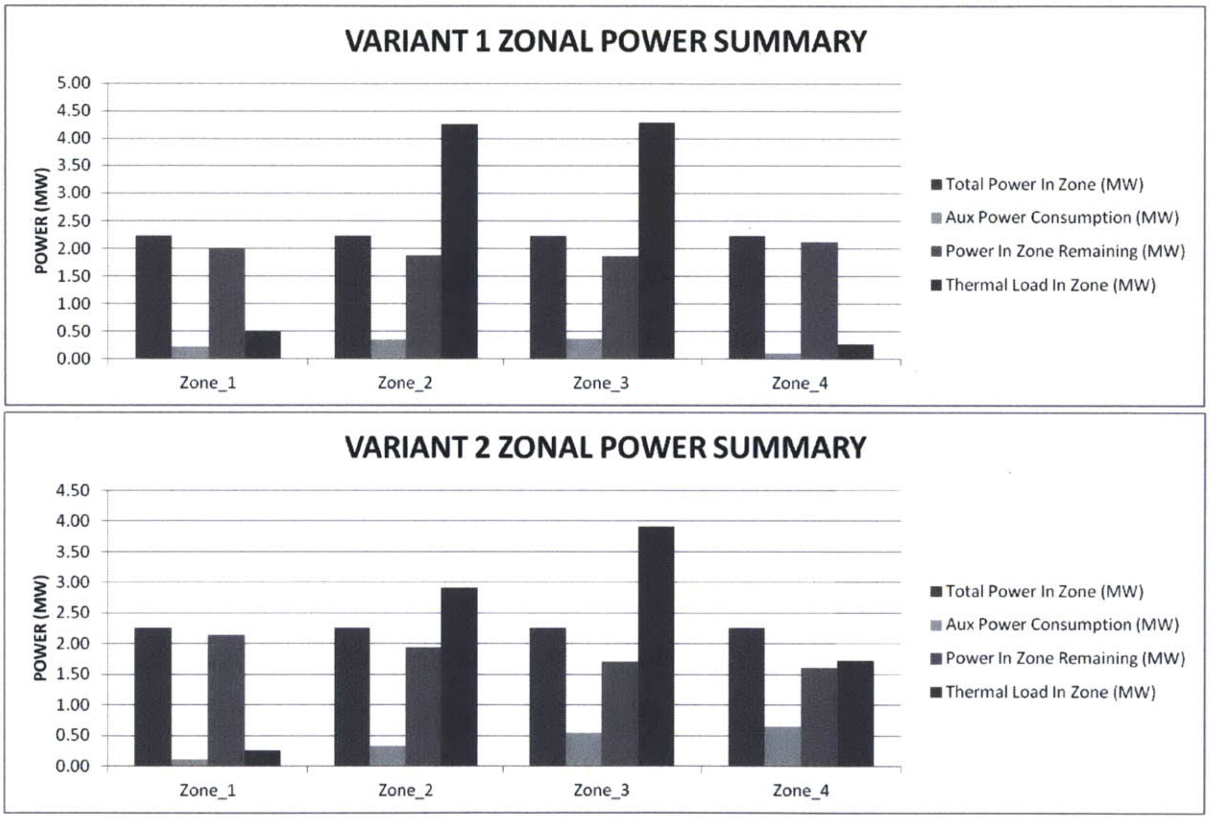

Figure 4-6: Thermal Load Comparison

The thermal loads are not concentrated into two zones in Variant 2 as they are in Variant 1. The difference is attributed to the propulsion motors and required power electronic equipment. Zones 2 and 3 in Variant 1 contain both PGMs and PMMs. While Variant 2 PGMs and PMM are separated into individual zones. The thermal load distribution developed by IPSDM can provide valuable insight to the design of the thermal management system.

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5. CONCLUSIONS

Overall, this thesis introduces a current method of ship design, proposes a new methodology to integrate IPS earlier in the process, and shows the implementation and development of IPS at the proposed stage of the ship design cycle. In an effort to implement and demonstrate the usefulness of the process, IPSDM was developed. The outputs of the IPSDM generate vital information at the earliest stages of design such as:

- Dimensions of machinery compartments and system
- Relative locations of compartments
- Machinery equipment lists
- Relative positions of equipment
- Thermal loads
- Electrical loads (supply and demand)
- Weight of system

By developing IPSDM, further insight into the validity of the process was provided, and its usefulness further demonstrated through case studies.

Through the execution of the case study, additional IPSDM insights were gained. IPSDM, in conjunction with ESSDT, aids in the determination of the principal characteristics of the entire ship via the maximum width of the machinery arrangement. The most significant insight gained from the case study was the feedback loop between hull dimensions and machinery compartment dimensions. Even though the maximum width difference between Variant 1 and 2 of Chapter 4 is minimal, the impact of the arrangement philosophy greatly affected the overall beam of the ship.

While performing the case study in conjunction with ESSDT, Variant 1 was produced with a maximum width of 63 feet which translated into a ship with a beam of 77 feet within ESSDT. Variant 2 was produced with a maximum width of 65 feet, but ESSDT produced a ship with a beam of 65 feet. The change in beam was due to the hull geometry. The beam of the vessel using Variant 1's design was increased to enclose all machinery components. The combination of machinery arrangement and hull geometry drove the beam requirement. The large increase in beam using Variant 1 was attributed to the original design philosophy of stack-up length, not width, would affect displacement. The opposite became apparent in the execution of the case study that displacement was greatly affected by the maximum stack-up width of the variant; therefore, the machinery arrangement in Variant 1 was reconfigured in an effort to decrease the beam at the expense of stack-up length. The original arrangement of Variant 1 took several hours to construct, but since the original arrangement of Variant 1was stored within the IPSDM MS Excel-based tool, reconfiguration time decreased to several minutes. The IPSDM MS Excel-based tool allowed for rapid reconfiguration of Variant 1 after receiving vital feedback from ESSDT. Figure 5-1 depicts examples of the reconfigured Variant 1 arrangement, and was generated by ESSDT via GRC Paramarine.

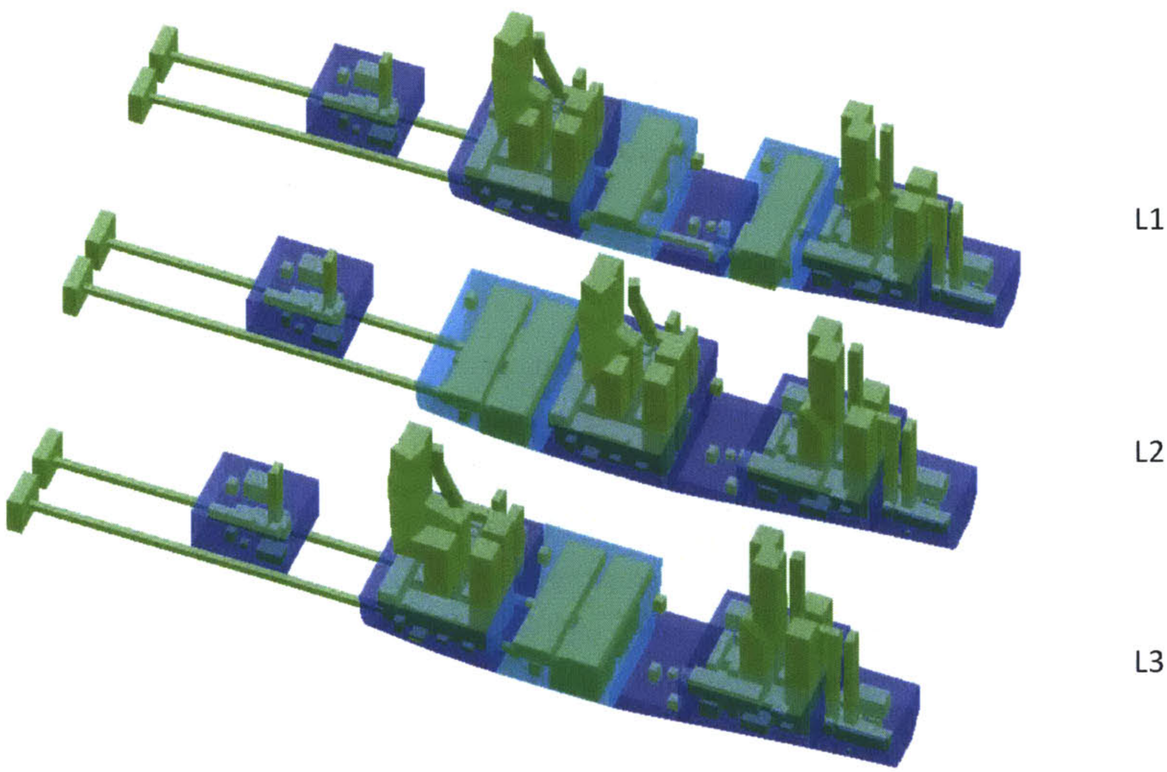

Figure 5-1: Variant 1 Reconfiguration Illustrations

The outputs of IPSDM are envisioned to be introduced into the ship design process as independent variables, altering the interdependencies of the historical ship design process. Altering the interdependencies allows for systems-of-systems tradeoffs to occur earlier in the design process in an effort to explore the design trade space. The benefit of utilizing IPSDM is to quantify energy tradeoffs at the earliest stage of the ship design in absence of a hull form and superstructure constraint. The method allows the ship designer to effectively "wrap" a hull and superstructure around the entire IPS design and the desired mission systems. The proposed process also identifies outputs along the process that aid in electrical load analysis, weight estimation, and thermal load estimation, which are products of decisions made along the process. Other ship design tools such as ESSDT and CSDT can take advantage of IPSDM's outputs in an effort to effectively populate the ship design trade space at the earliest stages of design.

5.1. FUTURE WORK

Areas of future work are identified in an effort to enhance the next generation of the IPSDM procedure. The following areas identified for further development are as follows:

1. Increase fidelity of the distribution system design. IPSDM allows for the selection of IPS architecture and associated equipment. It also provides guidance in zonal selection and power distribution. However, further attention is needed to integrate:
    a. The zonal distribution system and the mission systems
    b. The service highways
    c. Cable selection, routing, and weight estimation within each zone
    d. Dark-ship start mitigation
2. Expand IPSDM for the development of IPS for multihulls. Research into the arrangement of equipment in multihulls, especially SWATHs and catamarans, should be conducted to expand the machinery arrangement philosophy.
3. Incorporate specific fuel consumption (SFC) with IPSDM. PGMs are selected in IPSDM, and the SFCs of each IPS design could be estimated based on assumed operating conditions. Options of plant operation could be determined to optimize fuel consumption in an effort to compute economical or endurance ship speed based on PGM and hull form selection.
4. Utilize other software to allow for dragging and dropping of equipment. The most time consuming aspect of IPSDM within MS Excel is in the arrangement of equipment. Moving toward a more interactive arrangement interface will save on time to develop IPS arrangements.
5. Develop a direct GRC Paramarine plug-in for rapid insertion of equipment data. IPSDM is strongly coupled with ESSDT. Allowing IPSDM to automate the importation of the equipment database directly into GRC Paramarine without ESSDT would benefit ship designs at any stages of design. It would also facilitate the surface area and volume

computation of intake and exhaust ducts to better estimate efficiency reductions in prime movers due to head losses. This information could be fed back into IPSDM in order to adjust stack sizing, routing, and weight estimation.

6. Electrical load analysis of total ship including thermal management system. The electrical load estimation does not account for the power demand of the thermal management system or mission systems. This area could be tied into the distribution system fidelity.
7. Automate the process using algorithms synonymous with the process inherent in Intelligent Ship Arrangements (ISA) (Nick, 2008). Currently, the IPSDM process is executed manually by the user, but could be expanded to allow for design optimization.
8. Propulsors.
    a. Incorporate propulsive efficiency
    b. Incorporate waterjets

Incorporating the suggested areas of future work will increase the fidelity of system tradeoffs early in the ship design process.

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APPENDIX A: IPSDMv1.0 DESIGN TOOL USER MANUAL

This section presents the documentation associated with the MS Excel-based tool IPSDM version 1.0. The MS Excel-based tool utilizes the IPSDM process outlined in Chapter 2 to execute the process. The remainder of this section will focus on the internals of the tool and a tutorial.

A) SOFTWARE AND OPERATING SYSTEM REQUIREMENTS

MS Excel was chosen as the software for constructing the tool. MS Excel is common, inexpensive, and interfaces well with GRC Paramarine. IPSDMv1.0 requires the following components to operate:

- Windows XP or Windows 7
- MS Excel 2007
  - Automatic calculations must be suppressed to Manual in the Formula ribbon
    - Allowing automatic calculations will increase the computational/usage time especially when making selections and changes in the tool.
  - Excel Options>Formulas must be set to enable iterative calculation
    - Iterative calculations are present in IPSDMv1.0 especially during the arrangement of equipment. The default value of 100 iterations is acceptable.
    - Failure to turn on this feature will cause IPSDMv1.0 to not work properly, and may corrupt the workbook.

B) DATABASE STRUCTURE

The IPSDM process revolves around the equipment database. The equipment database is essential in utilizing IPSDM. Figure A-1 depicts an overview of the database structure.

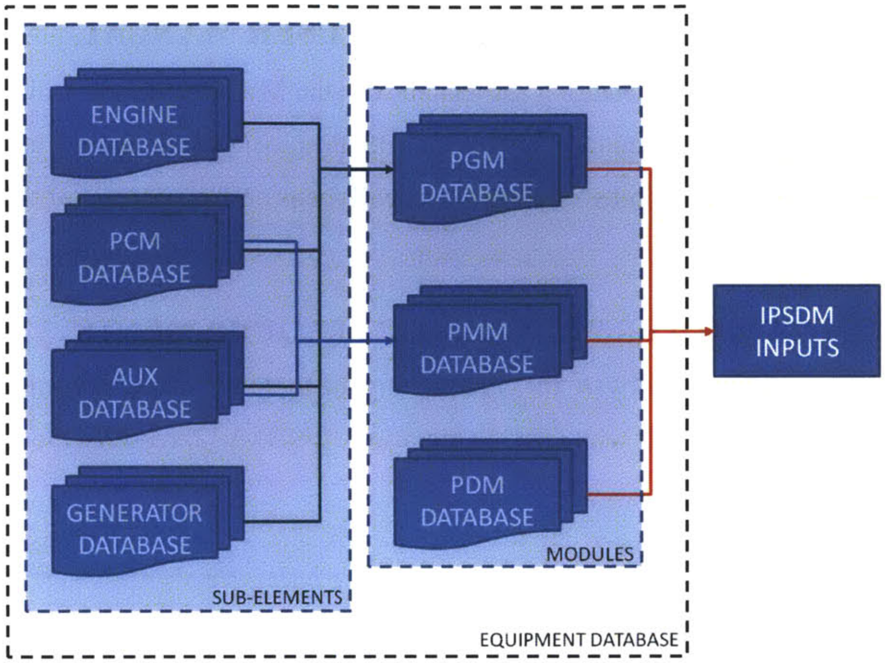


Figure A-1: IPSDM Database Structure

The solid lines within Figure A-1 indicate the flow of information. The dotted lines define the layers of the equipment database. The database structure is layered into sub-elements and modules. The purpose of layering the database is to incorporate flexibility into the tool. The flexibility allows the user to construct PGM and PMM modules with sub-elements. The PDM module is comprised of cabling selections and could be implemented as a sub-element, but instead was separated for use in constructing service highways. The sub-elements of the equipment database comprise of the following:

- Engine Database
    - Listing of prime movers and associated information
- PCM Database
    - Listing of all PCMs for motors and distribution
- AUX Database
    - Listing of all auxiliary equipment
        - Generator Lube Oil System
        - Engine Fuel System
        - Start Air System
        - Fire System

        - Bus Switchgear
        - Sea Water Cooling System
        - Engine Lube System
        - PMM Motor Lube Oil System
        - PMM Braking Resistors
        - PMM Power Filters
- Generator Database
    - Listing of generators

All equipment databases utilize the Table function within MS Excel. This function allows the user to expand the database without the need to change cell reference, allowing for automatic expansion during PGM, PMM, and Auxiliary equipment selection process. The following sections describe in detail the elements of the equipment database and the name as it appears MS Excel.

a) ENGINE DATABASE (MS Excel Name: EngineData)

The Engine Database comprises of prime movers and associated specifications. Geometric specifications (e.g. intake and exhaust geometry) are simplified in order to standardize the database. The following information is intended as a guide for use within the IPSDM database:

- Engine Model
    - Name and power output associated with prime mover
        - Name must not include spaces (e.g. GE_LM2500_25_1MW)
- Engine Type
    - Identify the type of prime mover
        - Gas turbine (GT), Diesel, etc.
        - Type must not include spaces
- Engine Brake Power
    - Brake power associated with prime mover under ideal conditions
- Engine RPM
    - RPM of prime mover at maximum continuous power
- Engine SFC
    - Optimal SFC at or near maximum brake power

- Engine Mass Flow
    - Air mass flow rate, if known
- Engine Exhaust Temperature
    - Exhaust temperature of prime mover, if known
- Engine Length
    - Length dimension
        - Referenced in the longitudinal direction
        - Maximum length of prime mover or enclosed module
- Engine Width
    - Width dimension
        - Referenced in the transverse direction
        - Maximum width of prime mover or enclosed module
- Engine Height
    - Height dimension
        - Maximum height of prime mover or enclosed module
- Engine Weight
    - Maximum weight of prime mover
- Intake Length
    - Assumed rectangular geometry
    - Length dimension of intake atop prime mover or enclosed module as depicted in Figure A-2

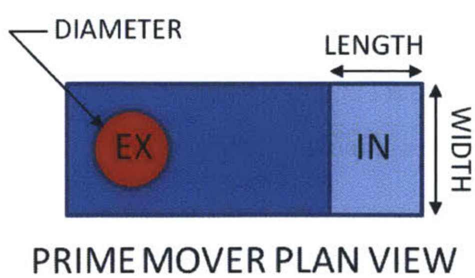


Figure A-2: Intake and Diameter Illustration

        - Referenced in the longitudinal direction
        - Known or estimated

            - Example: estimated as percentage of overall prime mover length for GT module

- Intake Width
    - Assumed rectangular geometry
    - Width dimension of intake atop prime mover or enclosed module
        - Referenced in the transverse direction
        - Known or estimated
            - Example: estimated as overall prime mover width for GT module
- Exhaust Diameter
    - Assumed circular geometry as depicted in Figure A-2
    - Diameter dimension of exhaust atop prime mover or enclosed module
        - Example: estimated as percentage of overall prime mover width for GT module

Notes should be included with each prime mover to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the Engine Database can be expanded (e.g. efficiencies, additional SFC points, etc.) so long as the dimensions of the prime mover, intake, exhaust diameters, and weight estimation remain intact. Those values are required within the IPSDM process.

b) PCM DATABASE (MS Excel Name: PCMData)

The PCM database comprises of the PCMs and associated specifications. Database includes PCM modules for distribution and PMM modules. Geometric specifications, where necessary, are simplified in order to standardize the database. The following information is intended as a guide for use within the IPSDM database:

- PCM Module
    - Name of PCM module and capacity in kW or MW
        - Name must not include spaces
        - Example: PCM4_1000, PCM2_2400, PCM_1MW
- PCM MW Load
    - Maximum electrical load capacity of PCM

- PCM Length
    - Length dimension
        - Referenced in the longitudinal direction
        - Maximum length of PCM enclosed module
- PCM Width
    - Width dimension
        - Referenced in the transverse direction
        - Maximum width of PCM enclosed module
- PCM Height
    - Height dimension
        - Maximum height of PCM enclosed module
- PCM Weight
    - Maximum weight of PCM module
- PCM Max Efficiency
    - Maximum operational efficiency of PCM
        - Known or estimated
- PCM Cruise Efficiency
    - Cruising operational efficiency of PCM
        - Known or estimated
- PCM Type
    - Type of PCM
        - Inverter
        - Rectifier
        - PCM for PMM motor
    - Example: PCM1_1200 > SS_DC_TO_DC_PCM
        - Ship service DC to DC converter
- PCM Cooling Load (kW)
    - Required cooling
    - Known or estimated based on PCM efficiency

Notes should be included with each PCM to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the PCM database can be expanded (e.g. operating voltages, power factor, derating factor, etc.) so long as the dimensions, efficiencies, and weight estimation of the PCM remain intact. Those values are required within the IPSDM process.

c) AUX DATABASE

The Auxiliary database is comprised of multiple databases as separate Table functions within MS Excel. Consolidating the auxiliaries into a single database was implemented to reduce the number or worksheets within IPSDMv1.0; however, the required information was standardized. Each auxiliary requires the following standard information:

- Name
  - Name of module
  - Name must not include spaces
- Type
  - Type of auxiliary
    - Example: Generator Lube System, Engine Fuel System, etc.
    - Required for PGM and PMM construction
- Length
  - Length dimension
    - Referenced in the longitudinal direction
    - Maximum length of enclosed module
- Width
  - Width dimension
    - Referenced in the transverse direction
    - Maximum width of enclosed module
- Height
  - Height dimension
    - Maximum height of enclosed module
- Weight
  - Maximum weight of module
- System kW Load

    - Maximum continuous electrical load of auxiliary equipment
        - Known or estimated
- Max Efficiency
    - Maximum operational efficiency of module
        - Known or estimated
- Cruise Efficiency
    - Cruising operational efficiency of module
        - Known or estimated

i) GENERATOR LUBE-OIL SYSTEM (MS Excel Name: GENLUBESYSData)

The generator lubrication system is envisioned as an external module intended to support the lubrication of the generator, if required. Notes should be included with each generator lubrication system module to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the generator lubrication system module can be expanded (e.g. operating voltages, temperature, etc.) so long as the dimensions, efficiencies, and weight estimation of the generator lubrication system module remain intact. Those values are required within the IPSDM process.

ii) ENGINE FUEL SYSTEM (MS Excel Name: ENGFUELSYSData)

The engine fuel system is envisioned as an external module intended to support the transfer and filtration of fuel to the prime mover. Notes should be included with each engine fuel system module to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the engine fuel system module can be expanded (e.g. operating voltages, temperature, etc.) so long as the dimensions, efficiencies, and weight estimation of the engine fuel system module remain intact. Those values are required within the IPSDM process.

iii) START-AIR SYSTEM (MS Excel Name: ENGFUELSYSData)

The start-air system is envisioned as an external module intended to support a pneumatic start of the prime mover, if needed. Notes should be included with each start-air system module to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the start-air system module can be expanded (e.g. operating voltages, temperature, etc.) so long as the dimensions, efficiencies, and weight estimation of the start-air system module remain intact. Those values are required within the IPSDM process.

iv) FIRE SYSTEM (MS Excel Name: FIRESYSData)

The fire system is envisioned as an external module intended to support the firemain distribution system via electric pumps. Notes should be included with each fire system module to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the fire system module can be expanded (e.g. operating voltages, temperature, etc.) so long as the dimensions, efficiencies, and weight estimation of the fire system module remain intact. Those values are required within the IPSDM process.

v) BUS SWITCHGEAR (MS Excel Name: BUSSWData)

The bus switchgear system is envisioned as an external module intended to support the electrical distribution system from the PGM generator. This auxiliary could be separated to include a stand-alone database or be included within the PCM database in future IPSDM versions. Additional specialized information can be included such as power capacity with the standard dimensional, weight, and efficiency information. Notes should be included with each bus switchgear to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the bus switchgear module can be expanded (e.g. operating voltages, temperature, etc.) so long as the dimensions, efficiencies, and weight estimation of the bus switchgear module remain intact. Those values are required within the IPSDM process.

vi) SEA WATER COOLING SYSTEM (MS Excel Name: SWSYSData)

The sea water cooling system is envisioned as an external module intended to support the cooling distribution system via electric pumps. Notes should be included with each sea water cooling system module to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the sea water cooling system module can be expanded (e.g. operating voltages, temperature, etc.) so long as the dimensions, efficiencies, and weight estimation of the sea water cooling system module remain intact. Those values are required within the IPSDM process.

vii) ENGINE LUBRICATION SYSTEM (MS Excel Name: ENGLUBESYSData)

The engine lubrication system is envisioned as an external module intended to support the lubrication of the prime mover, if needed. Notes should be included with each engine lubrication system module to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the engine lubrication system module can be expanded (e.g. operating voltages, temperature, etc.) so long as the dimensions, efficiencies, and weight estimation of the engine lubrication system module remain intact. Those values are required within the IPSDM process.

viii) PMM MOTOR LUBE-OIL SYSTEM (MS Excel Name: MOTORLUBData)

The motor lubrication system is envisioned as an external module intended to support the lubrication of the PMM motor, if needed. Notes should be included with each motor lubrication system module to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the motor lubrication system module can be expanded (e.g. operating voltages, temperature, etc.) so long as the dimensions, efficiencies, and weight estimation of the motor lubrication system module remain intact. Those values are required within the IPSDM process.

ix) PMM BRAKING RESISTORS (MS Excel Name: BRAKERESData)

The PMM braking resistor system is envisioned as an external module intended to support the control of the PMM motor, if needed. Notes should be included with each braking resistor system module to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the PMM braking resistor system module can be expanded (e.g. operating voltages, temperature, etc.) so long as the dimensions, efficiencies, and weight estimation of the PMM braking resistor system module remain intact. Those values are required within the IPSDM process.

x) PMM POWER FILTERS (MS Excel Name: PWRFILTData)

The power filter system is envisioned as an external module intended to support the control of the PMM motor, if needed. Notes should be included with each power filter system module to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the power filter system module can be expanded (e.g. operating voltages, temperature, etc.) so long as the dimensions, efficiencies, and weight estimation of the power filter system module remain intact. Those values are required within the IPSDM process.

d) GENERATOR DATABASE (MS Excel Name: GENERATORData)

The Generator database comprises of generators and associated specifications. Geometric specifications are simplified in order to standardize the database. The following information is intended as a guide for use within the IPSDM database:

- Name
  - Name of generator
    - Indicative of output and/or prime mover
    - Name must not include spaces
- Length
  - Length dimension
    - Referenced in the longitudinal direction
    - Maximum length of enclosed module
- Width
  - Width dimension
    - Referenced in the transverse direction
    - Maximum width of enclosed module
- Height
  - Height dimension
    - Maximum height of enclosed module
- Weight
  - Maximum weight of module
- System kW Load

    - Maximum continuous electrical load of auxiliary equipment
        - Known or estimated
- Max Efficiency
    - Maximum operational efficiency of module
        - Known or estimated
- Cruise Efficiency
    - Cruising operational efficiency of module
        - Known or estimated

Notes should be included with each generator to identify the source of information. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the generator database can be expanded (e.g. operating voltages, power factor, derating factor, etc.) so long as the dimensions, efficiencies, and weight estimation of the generator remain intact. Those values are required within the IPSDM process.

e) PGM DATABASE (MS Excel Name: PGMData)

The PGM database is comprised of equipment from the Engine database, Generator database, and Auxiliary database. Geometric specifications (e.g. intake and exhaust geometry) are simplified in order to standardize the database. The following information is included in each PGM for use within the IPSDM database:

- Engine Data
- Generator Data
- Generator Lubrication System
- Engine Fuel System
- Start Air System
- Fire System
    - If separate system is known
- Bus Switchgear
- PGM Subbase
    - If known size and weight of foundational structure for the prime mover generator set is known

- Sea Water Cooling System
    - If separate system is known

The PGM database is envisioned to be a flexible database where the user can choose from developed modules or create new modules. The following information depicts the overall parameters of the PGM within the IPSDM database:

- PGM Name
    - Name must not include spaces
- PGM Rating (MW)
    - Distributable power available from module
- PGM Bus Voltage
    - Identification of voltage
        - 4.16 kVAC, 13.8 kVAC, etc.
- Estimated Overall Length
    - Length estimation determined by prime mover and generator lengths
    - Later refined in the arrangement stage of IPSDM
- PGM Weight
    - Weight estimate as a sum of all equipment contained in the module

The equipment selection process relies on the information contained within the PGM module. Notes should also be included with each PGM to identify source of information or design rationale. The database is intended to store all equipment data, sources, and assumptions, and be flexible to allow for the capability of expansion. The information within the PGM can be expanded if it is pertinent to the IPS design, so long as the dimensions, efficiencies, and weight estimation of the generator remain intact. Those values are required within the IPSDM process.

f) PMM DATABASE (MS Excel Name: PMMData)

The PMM database is comprised of equipment from the PCM database and Auxiliary database. Geometric specifications are simplified in order to standardize the database. The following information is included in each PMM for use within the IPSDM database:

- Motor
- Associated PCM Module
- Associated Power Filter Module

- Associated Braking Resistors
    - Including number required
- PMM Motor Lube Oil System

The motor information is not listed in a separate database. The assumption is the PMM database revolves around the PMM motor and its specifications. The following information depicts the overall parameters of the motor within the IPSDM database:

- Name
    - Name of motor
        - Indicative of output
        - Name must not include spaces
- Length
    - Length dimension
        - Referenced in the longitudinal direction
        - Maximum length of enclosed motor
- Width
    - Width dimension
        - Referenced in the transverse direction
        - Maximum width of enclosed motor
- Height
    - Height dimension
        - Maximum height of enclosed motor
- Weight
    - Maximum weight of motor
- PMM Rating
    - Maximum continuous electrical load of PMM motor
        - Known or estimated
- PMM Maximum RPM
    - Maximum RPM output of motor
- Max Efficiency
    - Maximum operational efficiency of motor
        - Known or estimated

- Cruise Efficiency
    - Cruising operational efficiency of motor
        - Known or estimated

The PMM database is also envisioned to be a flexible database where the user can choose from developed modules or create new modules. The following information depicts the overall parameters of the PMM within the IPSDM database:

- PMM Name
    - Name must not include spaces
- PMM Rating (MW)
    - Motor maximum continuous rating
- PMM Voltage Type
    - Identification of voltage
        - AC or DC
- PGM Weight
    - Weight estimate as a sum of all equipment contained in the module
- PMM Propeller Type
    - Fixed pitch, controllable pitch, etc.

The equipment selection process relies on the information contained within the PMM module. Notes should also be included with each PMM to identify the source of information or design rationale. The information within the PMM can be expanded if it is pertinent to the IPS design, so long as the dimensions, efficiencies, and weight estimation of the generator remain intact. Those values are required within the IPSDM process.

g) PDM DATABASE (MS Excel Name: PDMData)

The PDM database contains the information related to cabling for service highway electrical transmission. Within IPSDMv1.0, this database is stand-alone and not utilized in the PGM or PMM module; however, future iterations of IPSDM can include cable definitions for PGMs and PMMs. The following information is intended as a guide for use within the IPSDM database:

- Name, with no spaces
- Rated voltage
- Rated current

- Resistance per unit length
- Weight per unit length

The information within the PDM database can be expanded if it is pertinent to the IPS design.

C) IPSDM WORKSHEET OPERATIONS

IPSDMv1.0 is comprised of several worksheets to execute the IPSDM design process. The design philosophy of multiple worksheet utilization was to isolate the data during the IPSDMv1.0 construction process for troubleshooting purposes. IPSDMv1.0 is comprised of the following worksheets as depicted in Figure A-3.

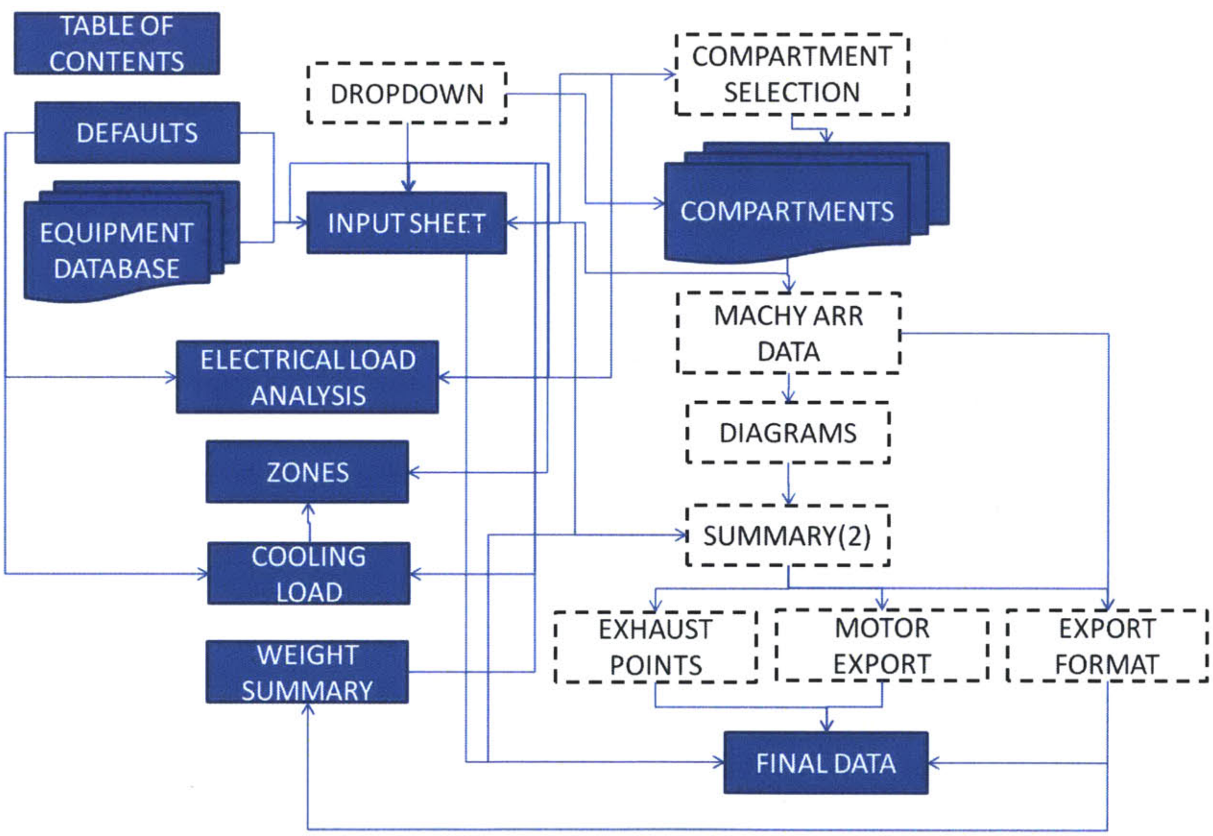


Figure A-3: IPSDMv1.0 Worksheets

Each box in Figure A-3 represents a worksheet constructed in MS Excel to execute the IPSDM design process. The boxes with a dotted outline indicate hidden worksheets for data collection and transfer. The data within the worksheets are linked to others via "hard" links, with an equal sign, or through arrays, denoted in MS Excel as "{}." The arrows in Figure A-3 indicate connections and data exchanges between worksheets.

The intent of presenting Figure A-3 is to highlight the complex connections and interdependencies of the IPS design within IPSDMv1.0. In future versions, the data exchange should be revised for more efficient transfer of information. The following sections identify the purpose of each worksheet and their respective inputs and outputs.

a) TABLE OF CONTENTS

The Table of Contents presents a high level overview of the IPSDM tool as well as hyperlinks to various worksheets for quick access.

b) DEFAULTS

The Defaults worksheet contains the required constant values for calculation during the IPSDM design process; however, these values can be overwritten should the user need to. The Defaults worksheet contains the estimated cable transmission efficiency and the assumptions of the typical operating loads for surface ships (NAVSEA, 1990). The DDS 310-1 loading factor table utilizes the Table function within MS Excel for sorting and automatic expansion. This worksheet also is a designated space for future default values, if needed. The following list contains inputs and outputs of this worksheet:

- Input
    - User defined defaults such as cable efficiency and electrical loading factors
- Output
    - Defaults utilized in the Input Sheet, Electrical Load Analysis Sheet, and the Cooling Load Estimation Sheet

c) EQUIPMENT DATABASE

The following are databases contained within the Equipment database:

- Engine Database
- PGM Database
- PMM Database
- PCM Database
- PDM Database
- Generator Database

- Auxiliary Database

See Appendix A Section B for more information on each. The following list contains inputs and outputs of this worksheet:

- Inputs
    - User defined equipment libraries
- Outputs
    - Required for computations and arrangements within the Input Sheet and Compartment Sheets 1-8

d) DROPDOWN

The Dropdown worksheet is a hidden sheet that contains lists for use with the Data Validation function within MS Excel. The Data Validation function allows for the insertion of dynamic dropdown lists to be imbedded in an individual cell. To view the dropdown references for all sheets: select the cell containing the dropdown list and go to Data>Data Validation>Settings. The following list contains inputs and outputs of this worksheet:

- Inputs
    - User defined choices for the Input Sheet and Compartment Sheets 1-8
    - Receives data from Input Sheet after compartment selections are defined by the user
- Outputs
    - Data supplied to Input and Compartment Sheets 1-8 for analysis

e) INPUT SHEET

The Input Sheet is at the heart of IPSDMv1.0 and is viewed as the master worksheet whereby all selections are made and viewed. Figure A-4 depicts the IPSDM process inherent within the Input Sheet.

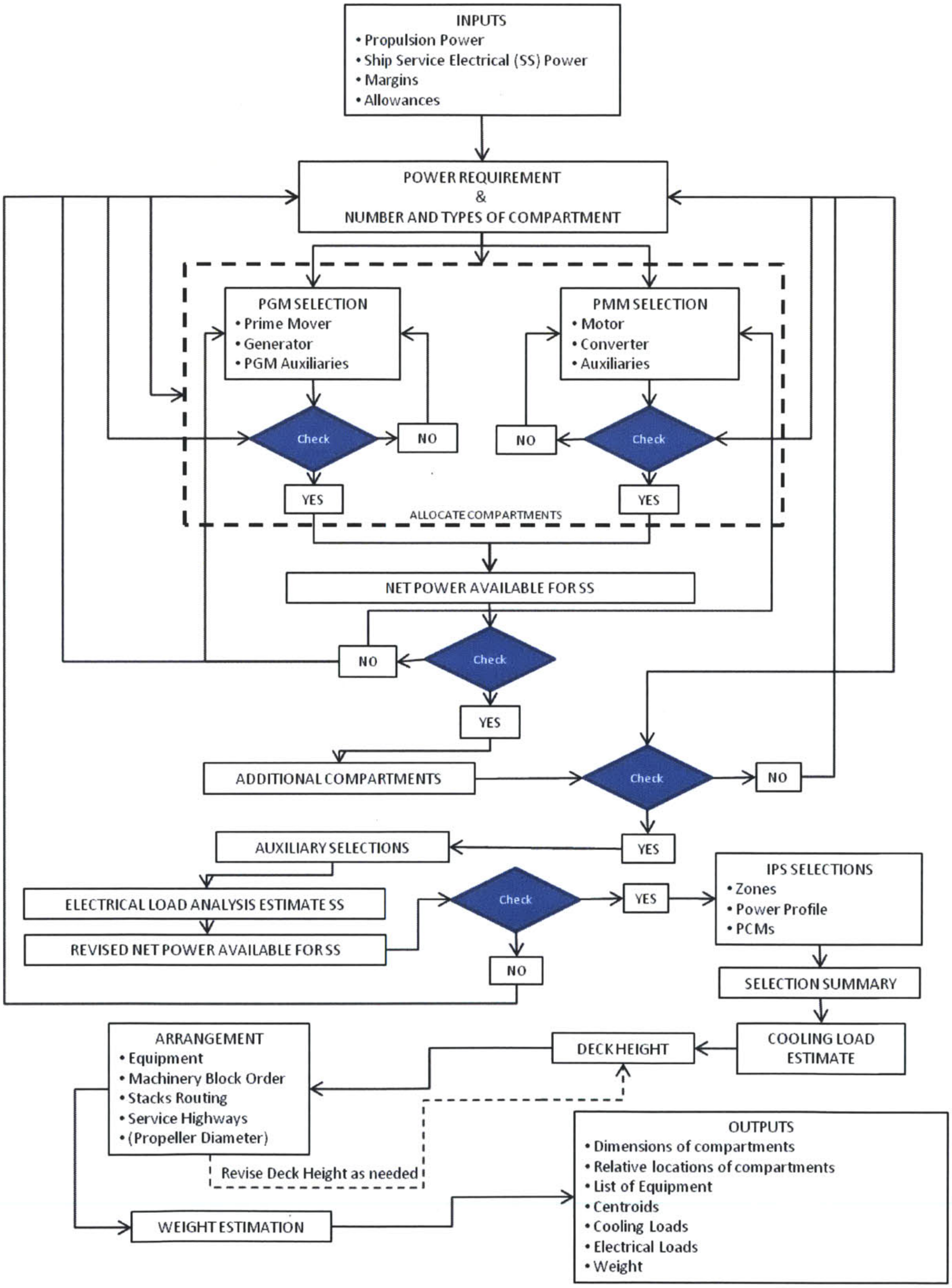


Figure A-4: IPSDM MS Excel Tool Process

This worksheet is comprised of seventeen individual sections. The sections are:

1. COMPARTMENT AND POWER REQUIREMENTS
    - See Chapter 3 Section 3.1 for further description
    - Values are input manually based on user preference
2. POWER GENERATION MODULE SELECTION
    - See Chapter 3 Section 3.2.1 for further information
    - Cable efficiency utilized to estimate distributable power
    - Maximum selection of 10 PGMs available from the PGM database
    - Inputs
        - Equipment Database
    - Outputs
        - Total Installed Power
        - Total Power Available with One Ship Service (SS) Generator Set Offline
        - Total Distributable Power Available with One SS Generator Set Offline
        - Value Compared to Power Requirement Target
        - Estimated Weight of all PGMs selected
        - Entries are also sent to Compartment Selection Sheet
3. PROPULSION MOTOR MODULE SELECTION
    - See Chapter 3 Section 3.2.2 for further information
    - Maximum selection of 10 PMMs available from the PMM database
    - Inputs
        - Equipment Database
    - Outputs
        - Estimated Input Propulsion Power Required
        - Total Propulsion Power
        - Propulsion Value Compared to Power Requirement Target
        - Estimated Net Power Available for SS
        - Net Power SS Value Compared to Power Requirement Target
        - Estimated Weight of all PMM selected
        - Entries also sent to Compartment Selection Sheet
4. ADDITIONAL COMPARTMENTS

- See Chapter 3 Section 3.6.3 for further information
- Inputs
    - Maximum of two user defined selections
- Outputs
    - Compares the additional compartment selections to the estimated total number of machinery compartments value in Compartment and Power Requirements section of the Input Sheet
    - Entries are sent to Compartment Selection Sheet

5. AUXILIARY COMPONENTS
    - See Chapter 3 Section 3.2.3 for further information
    - Inputs
        - Dropdown Sheet collects allocated spaces from Input Sheet and inserts space names into this section of the Input Sheet
        - Auxiliary equipment database
        - Maximum of two user defined selections per compartment
    - Outputs
        - Entries sent to Compartment Selection Sheet
6. ELECTRICAL LOAD ANALYSIS
    - See Chapter 3 Section 3.3 for further information
    - Inputs
        - Summary of electrical load analysis is provided by Electrical Load Analysis Sheet
            - Anchor, Shore, Cruising, Functional, and Emergency listed
    - Outputs
        - Total Auxiliary Power at Max Demand
        - Net power available updated with auxiliary power demand subtracted from net power available in the Section 3 in the Input Sheet
        - Net Power SS Value compared to power requirement
7. IPS SELECTIONS
    - See Chapter 3 Section 3.4 for further information
    - Inputs

- Estimated maximum margined electrical load from Section 3 of the Input Sheet
- Port and Starboard distribution value
    - Computed as ½ of the estimated maximum margined electrical load
- User defined electrical distribution system (i.e. AC ZEDS or DC ZEDS)
- User defined number of zones
- User defined zone to compartment allocation
    - Compartment list from Dropdown Sheet
    - Auxiliary power consumption listing from each compartment from the Electrical Load Analysis Sheet
- User defined power percentage allocation to each zone
- User defined IPS equipment selection from PCM Database
    - Maximum of three user defined AC-DC Rectifier or AC-AC Converter selections available
    - Maximum of two user defined DC-DC Converter or AC-AC Converter selections available for port and starboard bus distribution
    - Maximum of three user defined DC-AC Inverter selections available

- Outputs
    - Total power remaining in each zone
    - Entries and information associated with the IPS equipment selection is stored in the Compartment Selection Sheet

8. SELECTION SUMMARY
    - After all selections are defined, the user can view a summary of the equipment selected for each defined compartment via a dropdown menu provided by the Dropdown Sheet
    - Input
        - Data received from the Compartment Selection Sheet and displayed in the form of an array

- Output
    - None. This section acts as a check to the user for equipment selection before progressing further in the process

9. THERMAL LOAD ANALYSIS SUMMARY
    - See Chapter 3 Section 3.5 for further information
    - Inputs
        - Data from the Compartment Selection Sheet in the form of an array
        - Data from the Defaults Sheet for analysis
    - Outputs
        - Total thermal load
        - Thermal load distribution at Anchor, Shore, Cruising, Functional, and Emergency thermal profiles
        - Thermal load distribution for defined IPS zones
10. DECK HEIGHT DEFINITION
    - See Chapter 3 Section 3.6.4 for further information
    - Inputs
        - User defined number of decks and deck heights
    - Outputs
        - Data received by Compartment Sheets 1-8 and Summary(2) Sheet
11. COMPARTMENT ARRANGEMENT SUMMARY
    - Depicts the outputs of the machinery arrangement procedure for a maximum of eight compartments. Each compartment is located in individual sheets numbered 1-8
    - See Chapter 3 Section 3.6 for further information
    - Inputs
        - Compartment Sheets 1-8
    - Outputs
        - None. Purpose for visual summary only
12. MACHINERY BLOCK ORDER
    - Arrange machinery compartments in sequential order
    - See Chapter 3 Section 3.6 for further information

- Inputs
  - User defined machinery stack-up order
    - Number each compartment starting from bow to stern
  - Information extracted from Summary(2) Sheet
- Outputs
  - Machinery block order. Data sent to Export Format Sheet and Final Data Sheet

13. SHAFTING AND PROPELLERS

- See Chapter 3 Section 3.6 for further information
- Inputs
  - User defined factor for propeller diameter sizing
  - User defined additional shafting factor to extend shafts beyond machinery block
  - Information received from Summary(2) Sheet
- Outputs
  - Estimated maximum propeller diameter
  - Data sent to Motor Export Sheet for formatting and final insertion into the Final Data Sheet

14. STACKS

- See Chapter 3 Section 3.6 for further information
- Inputs
  - User defined polyline with a maximum of eight points for stack definition
  - Visual data presented from Summary(2) Sheet
- Outputs
  - Stack definition and routing for export. Data sent to Exhaust Points Sheet for formatting into the Final Data Sheet

15. SERVICE HIGHWAYS

- Develop service highways for all compartments
- User defined polylines to route service highway
- Input
  - User defined height and distance from centerline

- Data received from Summary(2) sheet

- Output
  - IPSDMv1.0 does not export the data
  - Intended for ESSDT and GRC Paramarine in future versions

16. WEIGHT ESTIMATION SUMMARY

- See Chapter 3 Section 3.7 for further information
- Input
  - Export Format Sheet and Compartment Selection Sheet collect and separate equipment into defined weight groups
    - IPSDMv1.0 partially estimates ESWBS 200, 300, and 500
- Output
  - Data contained in Final Data sheet for export to ESSDT

17. DESIGN SUMMARY

- Presents the summary of the IPSDM procedure
- Lists
  - Machinery block length
  - OMR lengths
  - Maximum width of design
  - Maximum height of design
  - Total installed brake power
  - Total distributable power
  - Total required propulsion power
  - Total shaft power
  - Net power available
  - Total auxiliary power at maximum demand
  - Estimated thermal load
  - Estimated total weight
  - Zonal distribution of power and thermal loads
- Output contained in Final Data Sheet for export to ESSDT

f) ELECTRICAL LOAD ANALYSIS SHEET

The electrical load analysis is discussed in detail in Chapter 3 Section 3.3, and conducted in accordance with DDS 310-1. The calculation process is automated with a search algorithm based on equipment type. The calculations are performed on a compartment by compartment basis as function of the equipment contained within them. The following list contains inputs and outputs of this worksheet:

- Inputs
  - Data associated with the selection of equipment is provided by the Compartment Selection Sheet, Equipment Database, and the Defaults Sheet
- Outputs
  - Total auxiliary power at maximum demand
  - Net power available updated with auxiliary power demand subtracted from net power available from Section 3 of the Input Sheet
  - Net power SS value compared to power requirement

g) ZONES SHEET

The Zones sheet is a hidden sheet that collects the zonal allocations from the Input Sheet, Electrical Load Analysis Sheet, Cooling Load Analysis Sheet, and the Weight Summary Sheet. The weight estimation data was added for future versions in an attempt to provide an initial weight distribution as a function of user defined zones. The following list contains inputs and outputs of this worksheet:

- Inputs
  - User defined zonal allocations from the Input Sheet
  - Outputs from the Cooling Load Estimation Sheet, Electrical Load Analysis Sheet, and Weight Summary Sheet
- Outputs
  - Total power in zone
  - Auxiliary power consumption per zone
  - Power remaining in zone
  - Thermal load in zone
  - Bar plot of outputs for Design Summary section of the Input Sheet

h) COOLING LOAD SHEET

The thermal load analysis is discussed in detail in Chapter 3 Section 3.5, and conducted in accordance with DDS 310-1. The calculation process is automated with a search algorithm based on equipment type. The calculations are performed on a compartment by compartment basis as function of the equipment contained within them. The following list contains inputs and outputs of this worksheet:

- Inputs
    - Data associated with the selection of equipment is provided by the Compartment Selection Sheet, Equipment Database, and the Defaults Sheet
- Outputs
    - Total thermal load
    - Thermal load distribution at Anchor, Shore, Cruising, Functional, and Emergency thermal profiles
    - Thermal load distribution for defined IPS zones

i) WEIGHT SUMMARY SHEET

The weight estimation process is discussed in Chapter 3 Section 3.7. The Weight Summary Sheet displays the selected equipment, their respective weights, and the appropriate ESWBS group. The weight breakdown is presented in a list of all equipment selected and compartment by compartment. The ESWBS groups are summed to provide the total weight estimation of the system. The following list contains inputs and outputs of this worksheet:

- Inputs
    - Data from the Export Format Sheet and Compartment Selection Sheet to collect and separate equipment into defined weight groups
        - IPSDMv1.0 partially estimates ESWBS 200, 300, and 500
    - Output
        - Data contained in Final Data Sheet for export to ESSDT
        - Summarized data is also displayed in the Input Sheet

j) COMPARTMENT SELECTION SHEET

The Compartment Selection Sheet is a hidden sheet that collects all user inputs and selections from the Input Sheet. This sheet stores the information for distribution as arrays to other sheets within IPSDMv1.0. The data within this sheet is used to calculate the electrical load of the auxiliary equipment, the cooling load, and acts as input into the compartment arrangement sheets. The following list contains inputs and outputs of this worksheet:

- Input
    - Data is received from the Input Sheet and Equipment Databases
- Output
    - Data is sent to Compartment Sheets 1-8, Electrical Load Analysis Sheet, Cooling Load Sheet, and other areas of the Input Sheet

k) COMPARTMENT SHEETS 1-8

The Compartments 1-8 sheets contain the necessary data to perform the machinery arrangements. There are a total of eight identical sheets that contain the compartment name and equipment selected to occupy that compartment. Features built into those sheets allow the user to place, rotate, and translate equipment. For machinery arrangement guidelines see Chapter 3 Section 3.6. The following list contains inputs and outputs of this worksheet:

- Inputs
    - Data from the Compartment Selection Sheet and elements from the Dropdown Sheet for arrangement selections
- Outputs
    - Location of equipment in each space
    - Dimensions of each compartment
    - Data sent to Machy Arr Data Sheet for formatting

l) MACHY ARR DATA SHEET

The Machy Arr Data sheet a hidden worksheet that collects all of the machinery arrangement data. It also reorients the reference value for all equipment within a compartment to the centroid the compartment. The reorientation allows the user in the Input Sheet to order the compartments during the stack-up process in Section 12 of the Input Sheet. The following list contains inputs and outputs of this worksheet:

- Inputs
    - Primary inputs are Compartment Sheets 1-8
- Outputs

    - Data is sent to the Diagrams Sheet for insertion to the Summary(2) Sheet

m) DIAGRAMS SHEET

The Diagrams Sheet collects the information from the Machy Arr Data Sheet, and applies a filter algorithm to separate the OMRs from the AMRs and MMRs. This data is then sent to the Summary(2) sheet for further use. The following list contains inputs and outputs of this worksheet:

- Inputs
    - Data related to position of equipment from the Machy Arr Data Sheet
- Outputs
    - Equipment data is separated and formatted for plotting in the Summary(2) Sheet

n) SUMMARY(2) SHEET

The Summary(2) Sheet is a hidden sheet that collects the equipment selection data, the user defined inputs, and equipment position data in order to plot the equipment and compartments into a single machinery block or separate OMRs. The plots that appear n the Input Sheet from Sections 12 to 15, and are referenced to the Summary(2) sheet. The following list contains inputs and outputs of this worksheet:

- Inputs
    - Data related to position of equipment from the Input Sheet, Compartment Sheets 1-8, and the Diagrams Sheet
- Outputs
    - Equipment data is separated and formatted for plotting
    - Copies of plots are sent to the Input Sheet for visualization

o) EXHAUST POINTS SHEET

The Exhaust Points Sheet is a hidden sheet that collects all of the polyline data associated with the stack routing in the Input Sheet. The data from the Input Sheet is collected and formatted for insertion to the Final Data Sheet. The following list contains inputs and outputs of this worksheet:

- Inputs

  - User defined polyline points from the Input Sheet and diameter information from the Summary(2) Sheet
- Outputs
  - Data is collected, formatted, and sent to the Final Data Sheet

p) MOTOR EXPORT SHEET

The Motor Export Sheet is a hidden sheet that formats the motor data with the estimated maximum diameter propeller information. The following list contains inputs and outputs of this worksheet:

- Inputs
  - Data from the Summary(2) Sheet and Input Sheet is collected and formatted
- Outputs
  - Data is sent to the Final Data Sheet for export to ESSDT

q) EXPORT FORMAT SHEET

The Export Format Sheet is a hidden sheet that formats the data collected from the Machy Arr Sheet and Summary(2) Sheet. The following list contains inputs and outputs of this worksheet:

- Inputs
  - Data from the Machy Arr Sheet and Summary(2) sheet
- Outputs
  - Data formatted for export as an array to the Final Data Sheet

r) FINAL DATA SHEET

The Final Data Sheet is the final sheet that contains all pertinent information about the IPS design. The sheet is specially formatted in order to be used within ESSDT. ESSDT requires the position of data to be located within specific regions of the worksheet for automatic extraction. The following list contains inputs and outputs of this worksheet:

- Inputs
  - Data from the Summary(2) Sheet, Input Sheet, Export Format Sheet, Motor Export Sheet, and Exhaust Points Sheet comprise the summary of the design
- Outputs
  - Data within the sheet is sent to an IPS database for insertion to ESSDT

D) TUTORIALS

The following section introduces instruction for the user on the application of IPSDMv1.0. The tutorial will cover user interfaces and methods of data input and extraction.

1. OPENING IPSDM MS EXCEL FILE

As a precaution, open MS Excel version 2007 before opening the IPSDMv1.0 file. Implement the following:

a. Go to the ribbon bar and click the Windows button at the top right of the workbook as shown in Figure A-5.

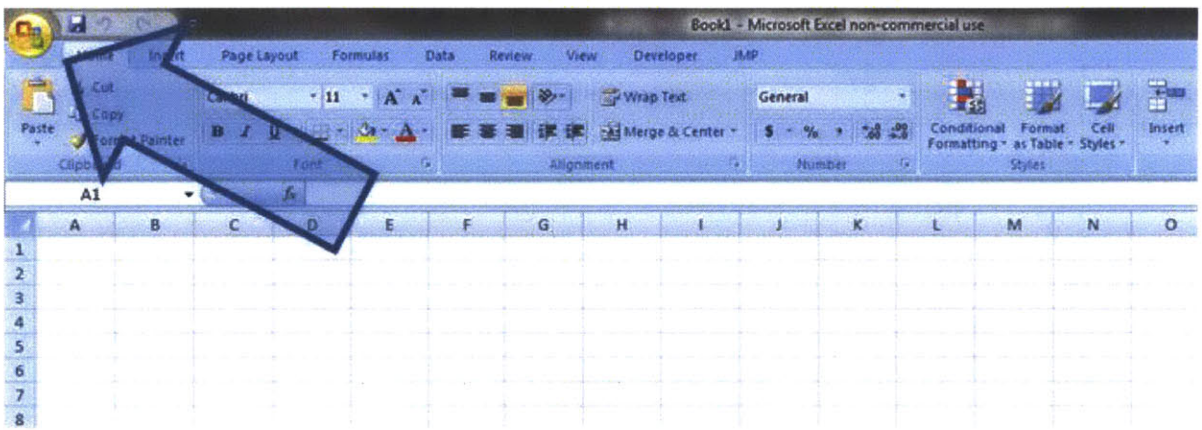


Figure A-5: Windows Button

b. Go to Excel Options>Formulas and check the "Enable iterative calculation" as shown in Figure A-6. Enabling iterative calculation will allow IPSDMv1.0 to function properly.

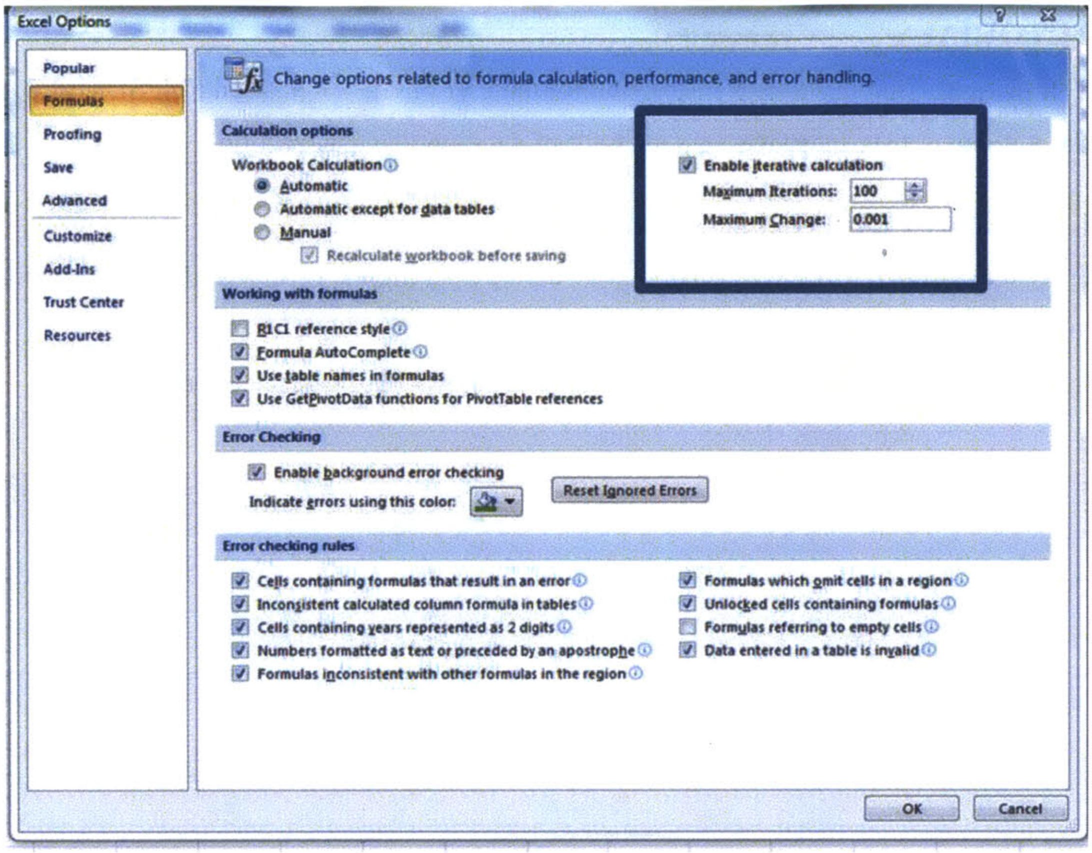


Figure A-6: Enable Iterative Calculation

c. Select OK and exit Excel Options

d. Go to the Formulas tab on the ribbon bar and select Calculation Options. Change the calculation option from Automatic to Manual as show in Figure A-7. Changing the calculation settings to manual will allow for smoother operation.

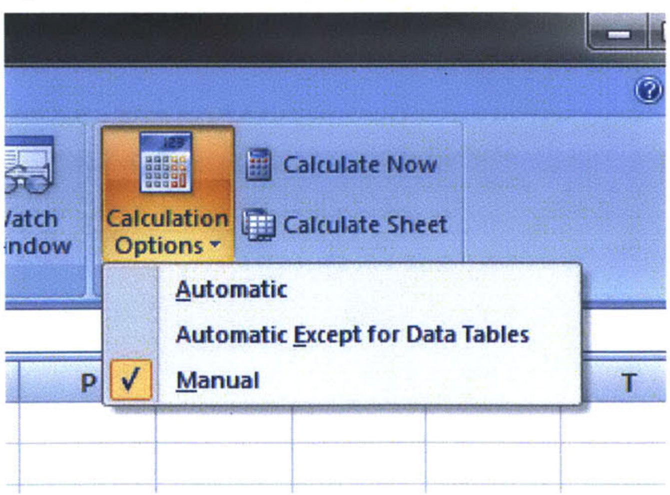


Figure A-7: Calculation Option

e. Locate and open the IPSDMv1.0 MS Excel file and enable macros.

2. NAVIGATING IPSDMv1.0

The Table of Contents worksheet provides the user with hyperlinks to all areas of IPSDMv1.0 as shown in Figure A-8. It also identifies hidden sheets should the user require access.

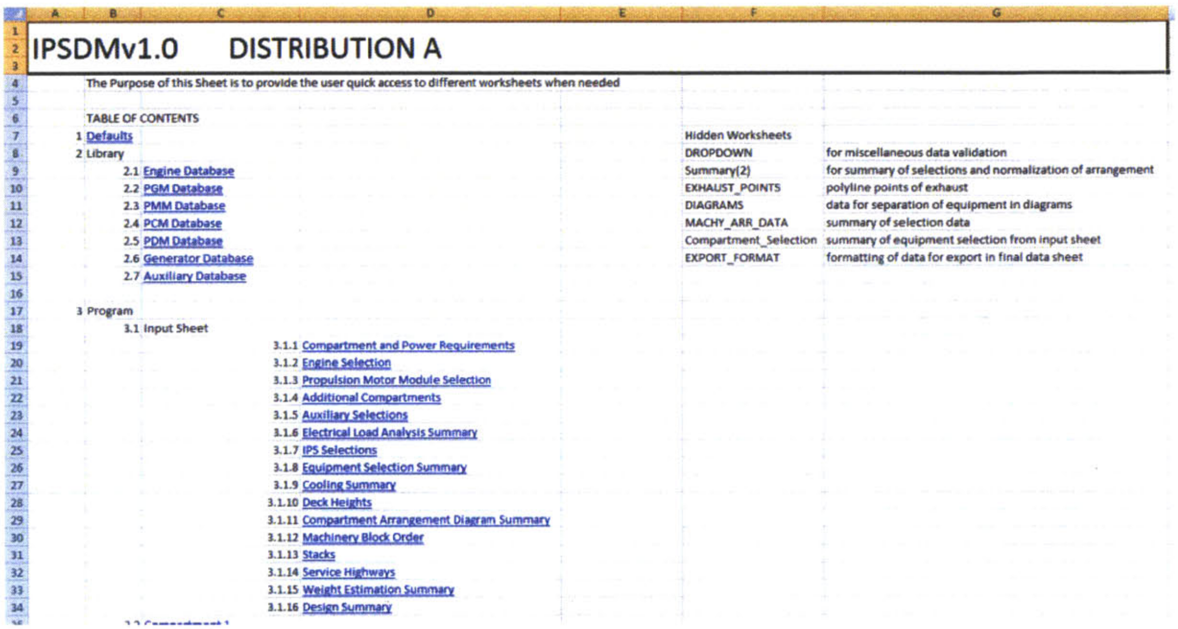


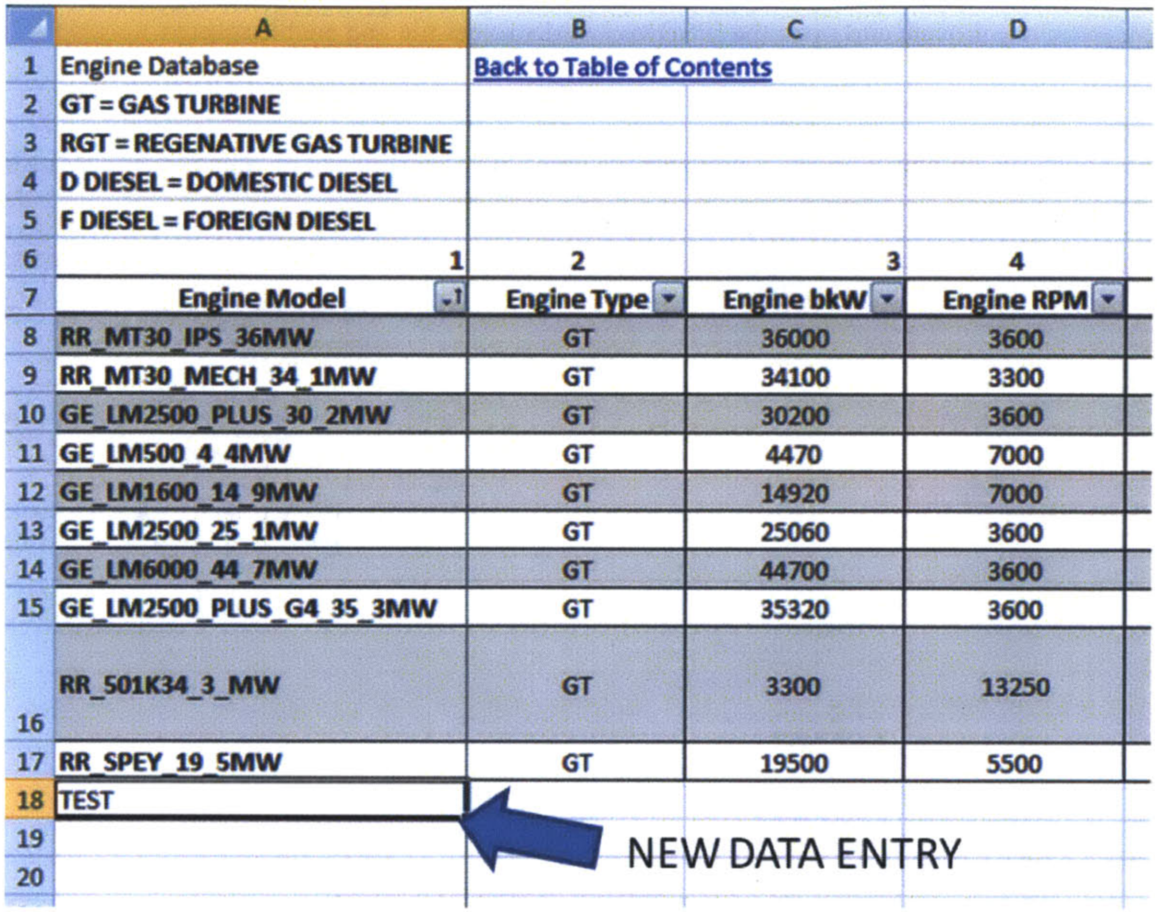
Figure A-8: IPSDMv1.0 Table of Contents

3. DATABASE ENTRY

IPSDMv1.0 contains a preloaded database with equipment. The equipment within each figure of this section was collected from open sources (i.e. online vendor fact sheets). The equipment units are in metric; however, the input sheet converts the dimensional data to English units for direct implementation into ESSDT. To add or change information to the database, the following procedure must be followed:

a. Adding data to Engine Database, Generator Database, PCM Database, and PDM Database

  i. To add data simply select the row below the last data entry and begin entering the corresponding data as dictated by the column titles as shown in Figure A-9.



	A	B	C	D
1	Engine Database	Back to Table of Contents		
2	GT = GAS TURBINE			
3	RGT = REGENATIVE GAS TURBINE			
4	D DIESEL = DOMESTIC DIESEL			
5	F DIESEL = FOREIGN DIESEL			
6	1	2	3	4
7	Engine Model	Engine Type	Engine bkW	Engine RPM
8	RR_MT30_IPS_36MW	GT	36000	3600
9	RR_MT30_MECH_34_1MW	GT	34100	3300
10	GE_LM2500_PLUS_30_2MW	GT	30200	3600
11	GE_LM500_4_4MW	GT	4470	7000
12	GE_LM1600_14_9MW	GT	14920	7000
13	GE_LM2500_25_1MW	GT	25060	3600
14	GE_LM6000_44_7MW	GT	44700	3600
15	GE_LM2500_PLUS_G4_35_3MW	GT	35320	3600
16	RR_501K34_3_MW	GT	3300	13250
17	RR_SPEY_19_5MW	GT	19500	5500
18	TEST			
19				
20				

Figure A-9: PGM, Generator, PCM, and PDM Database Entry

ii. With the MS Excel Table function, after entering data, the database automatically updates to store the new data. Storage is indicated when the row formatting matches the pattern of the data above as shown in Figure A-10.

	A	B	C	D
1	Engine Database	Back to Table of Contents		
2	GT = GAS TURBINE			
3	RGT = REGENATIVE GAS TURBINE			
4	D DIESEL = DOMESTIC DIESEL			
5	F DIESEL = FOREIGN DIESEL			
6	1	2	3	4
7	Engine Model	Engine Type	Engine bkW	Engine RPM
8	RR_MT30_IPS_36MW	GT	36000	3600
9	RR_MT30_MECH_34_1MW	GT	34100	3300
10	GE_LM2500_PLUS_30_2MW	GT	30200	3600
11	GE_LM500_4_4MW	GT	4470	7000
12	GE_LM1600_14_9MW	GT	14920	7000
13	GE_LM2500_25_1MW	GT	25060	3600
14	GE_LM6000_44_7MW	GT	44700	3600
15	GE_LM2500_PLUS_G4_35_3MW	GT	35320	3600
16	RR_501K34_3_MW	GT	3300	13250
17	RR_SPEY_19_5MW	GT	19500	5500
18	TEST			
19				
20				

Figure A-10: Database Update

iii. The numbers above each column in the database correspond to links in the form of arrays and VLOOKUP functions within MS Excel. Adding a new column between the numbered columns is not recommended because it will alter the data exchange within the program. New columns should be added after the numbered columns.

b. Adding data to the Auxiliary Database

i. The Auxiliary database is a collection of multiple databases each using the Table function. See Appendix A Section B Part C for more information.

ii. Each table allows for a maximum of 10 entries.

iii. To add data simply select the row below the last data entry and begin entering the corresponding data as dictated by the column titles as shown in Figure A-11.

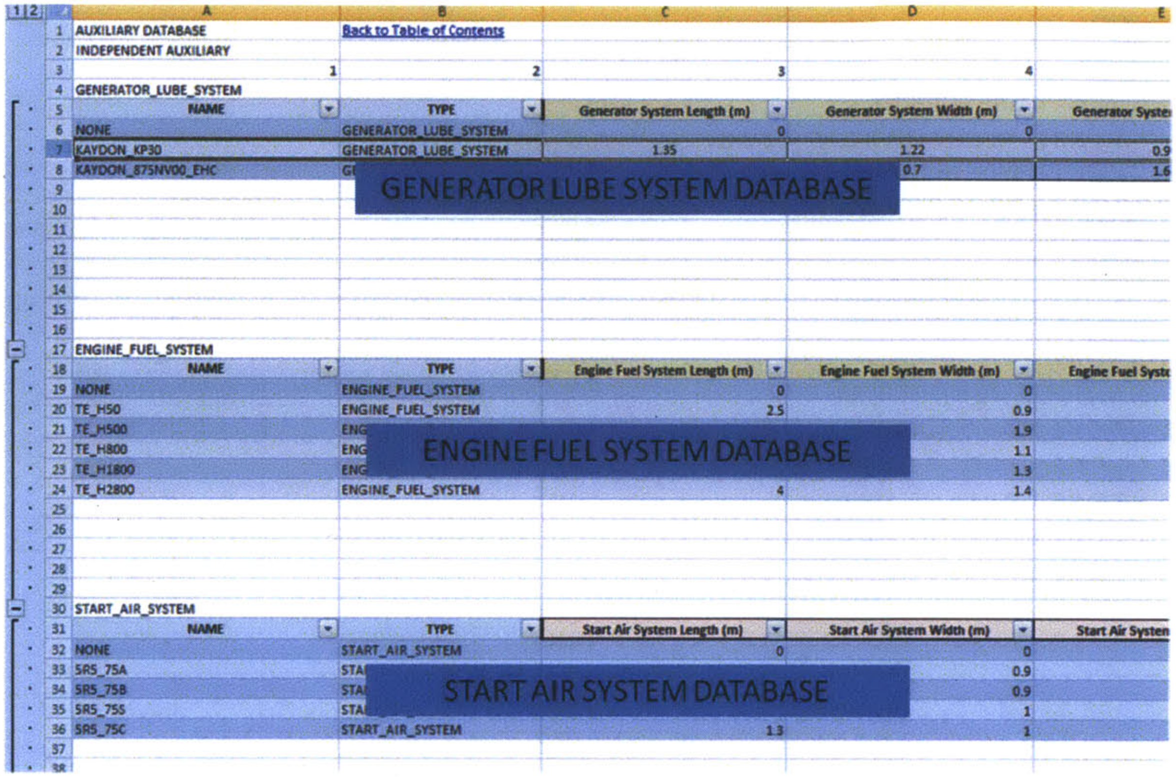


Figure A-11: Auxiliary Database Entry

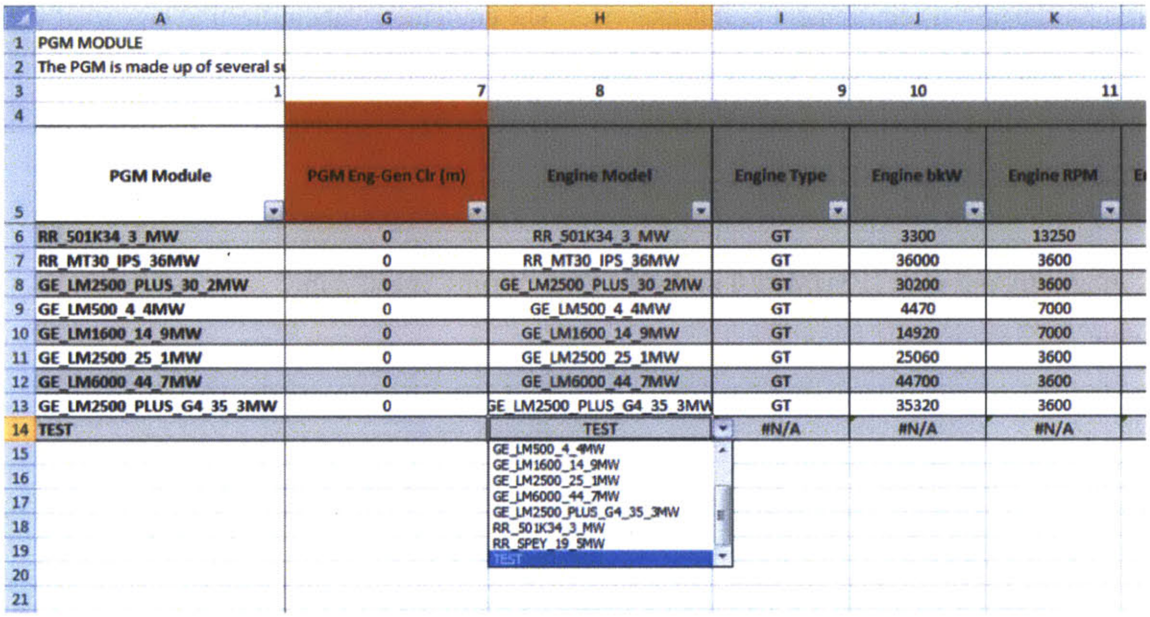
iv. With the MS Excel Table function, after entering data, the database automatically updates to store the new data. Storage is indicated when the row formatting matches the pattern of the data above.

v. The numbers above each column in the database correspond to links in the form of arrays and VLOOKUP functions within MS Excel. Adding a new column between the numbered columns is not recommended because it will alter the data exchange within the program. New columns should be added after the numbered columns.

c. Adding data to the PGM and PMM Databases

i. Adding data requires the use of the Engine, Generator, PCM, and Aux databases. The PGM and PMM database is separated into sections that allow the user to construct PGMs and PMMs. Under each column requiring a name, is a dropdown menu.

ii. To add data simply select the row below the last data entry and begin entering the corresponding data as dictated by the column titles as shown in Figure A-12.



	A	G	H	I	J	K
1	PGM MODULE					
2	The PGM is made up of several s					
3	1	7	8	9	10	11
4						
5	PGM Module	PGM Eng-Gen Clr (m)	Engine Model	Engine Type	Engine bkW	Engine RPM
6	RR_501K34_3_MW	0	RR_501K34_3_MW	GT	3300	13250
7	RR_MT30_IPS_36MW	0	RR_MT30_IPS_36MW	GT	36000	3600
8	GE_LM2500_PLUS_30_2MW	0	GE_LM2500_PLUS_30_2MW	GT	30200	3600
9	GE_LM500_4_4MW	0	GE_LM500_4_4MW	GT	4470	7000
10	GE_LM1600_14_9MW	0	GE_LM1600_14_9MW	GT	14920	7000
11	GE_LM2500_25_1MW	0	GE_LM2500_25_1MW	GT	25060	3600
12	GE_LM6000_44_7MW	0	GE_LM6000_44_7MW	GT	44700	3600
13	GE_LM2500_PLUS_G4_35_3MW	0	GE_LM2500_PLUS_G4_35_3MW	GT	35320	3600
14	TEST		TEST	#N/A	#N/A	#N/A

Figure A-12: PGM and PMM Database Entry

iii. The columns following the equipment selections will automatically recall and populate the data associated with the chosen equipment for a particular module.

iv. With the MS Excel Table function, after entering data, the database automatically updates to store the new data. Storage is indicated when the row formatting matches the pattern of the data above.

v. The numbers above each column in the database correspond to links in the form of arrays and VLOOKUP functions within MS Excel. Adding a new column between the numbered columns is not recommended because it will alter the data exchange within the program. New columns should be added after the numbered columns.

4. DESIGN TUTORIAL

This section provides instruction on the application of IPSDMv1.0 through a machinery arrangement design tutorial. The tutorial allows the user to become acquainted with the features of the Input and Compartment Sheets within IPSDMv1.0.

The tutorial revolves around the estimated required power requirement of a Type 45 destroyer. Type 45 is a new class of destroyers built for the United Kingdom's Royal Navy, and utilizes IPS for its ship service and propulsion system ("Type 45 destroyer," 2012). Type 45 serves as the basis for the power requirement in this exercise. The equipment data utilized to construct the IPS design is open source, and does not reflect the actual design and arrangement of the machinery plant within the Type 45 destroyer. The purpose of this tutorial is to instruct the user on the application of IPSDMv1.0.

1. Begin by opening IPSDMv1.0 and select the "Input Sheet" tab.

Figure A-13 depicts the Input Sheet.

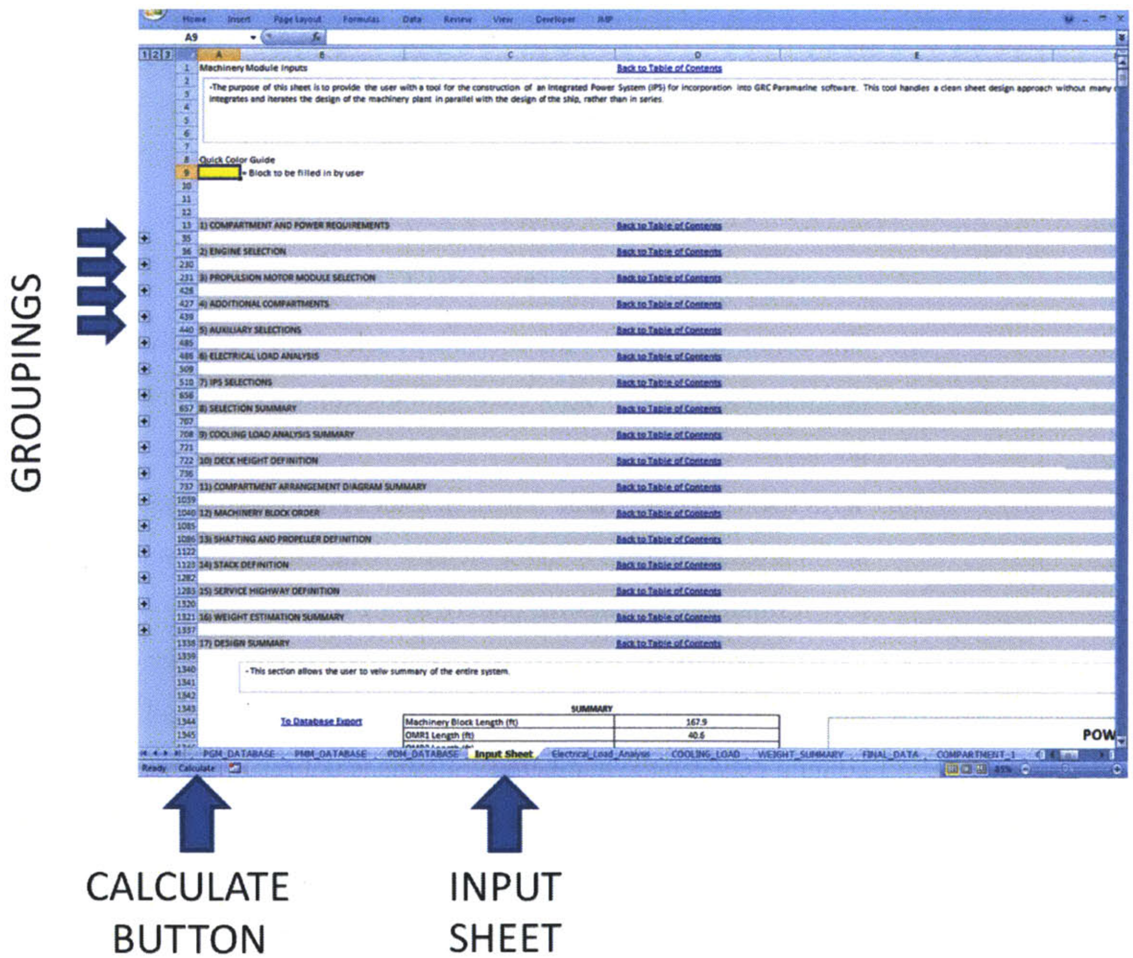


Figure A-13: Input Sheet

Figure A-13 shows a collapsed view of the Input Sheet. The Input Sheet is split into 17 individual sections. The 17 individual sections are as follows:

1. COMPARTMENT AND POWER REQUIREMENTS
2. POWER GENERATION MODULE SELECTION
3. PROPULSION MOTOR MODULE SELECTION
4. ADDITIONAL COMPARTMENTS
5. AUXILIARY SELECTIONS
6. ELECTRICAL LOAD ANALYSIS
7. IPS SELECTIONS
8. SELECTION SUMMARY
9. COOLING LOAD ANALYSIS SUMMARY
10. DECK HEIGHT DEFINITION
11. COMPARTMENT ARRANGEMENT SUMMARY
12. MACHINERY BLOCK ORDER
13. SHAFTING AND PROPELLER DEFINITION
14. STACK DEFINITION
15. SERVICE HIGHWAY DEFINITION
16. WEIGHT ESTIMATION SUMMARY
17. DESIGN SUMMARY

The sections and the information contained inside Figure A-13 are grouped. To expand the sections, simply click on the "+" to the left of the desired section. The Calculation button appears in the bottom left corner of sheet after following the steps in Appendix A Section D Part 1. It also appears in the same location within every sheet of IPSDMv1.0. In order to update the program after making an input, the Calculate button must be clicked to execute the calculations and update the selections.

2. Expand Section 1) COMPARTMENT AND POWER REQUIREMENTS

The power requirement and margins for this tutorial were estimated using Type 45 as a basis and appear as the following:

- Propulsion Power = 38 MW
- Ship Service Electrical Power = 4 MW
- Design Margin = 10%
- Service Life Allowance = 5%

The number of compartments and their arrangement will be designed as follows:

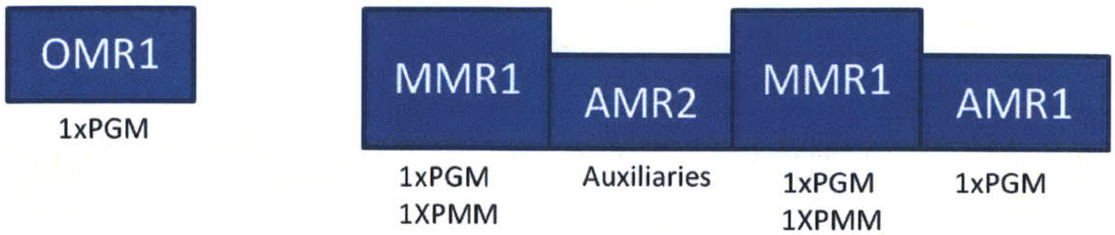


Figure A-14: Tutorial Arrangement Cartoon

As shown in Figure A-14, this design will have the following compartments: 2xMMRs, 2xAMRs, and 1xOMR. For more information see Chapter 3 Section 3.1 related to the philosophy behind the power and compartment requirements. Enter data into the yellow cells and select the Calculate button as shown in Figure A-15.

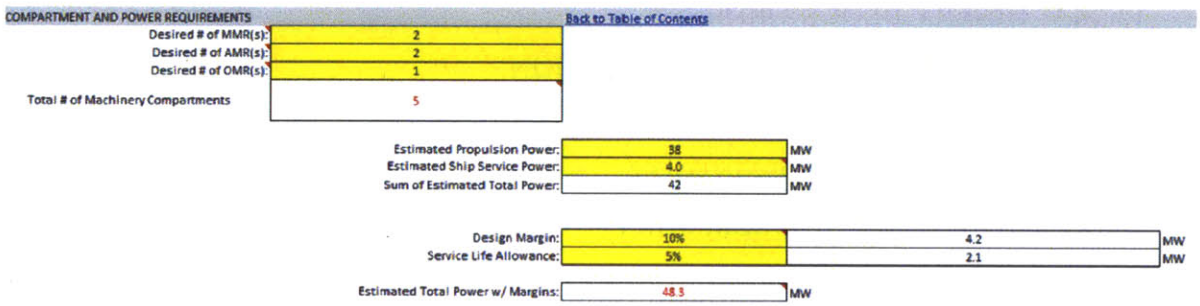


Figure A-15: Compartments and Power Requirement

All cells highlighted in yellow within IPSDMv1.0 require a user input in the form of a direct entry or dropdown selection. To clear a dropdown or direct entry, the user can select the input cell and hit Delete on the keyboard. All other cells contain embedded formulas to execute IPSDMv1.0.

3. Expand Section 2) ENGINE SELECTION

The Engine Selection section allows the user to select PGMs from the PGM database to meet the power requirement and place them into specific user defined compartments. A default cable efficiency is also depicted at the top of the Engine Selection section. The cable efficiency can be changed in the Defaults sheet. The cable efficiency for this exercise is assumed to be 0.98. Select the following PGMs and associated compartments to satisfy the power and compartment requirements:

- MMR1>GE_LM2500_25_1MW>ONLINE>PROPULSION

- MMR2>GE_LM2500_25_1MW>ONLINE>PROPULSION
- AMR1>RR_501K34_3_MW>ONLINE>SHIP_SERVICE
- OMR1>RR_501K34_3_MW>OFFLINE>SHIP_SERVICE

Three of the four engines are assumed to be online at this instance in time. The online and offline designation indicates which PGM is assumed to be the N+1 generator. See Chapter 3 Section 3.2.1 for more information. The Propulsion and Ship Service designation refers to the ESWBS weight category for weight accounting. The prime mover, generator, and auxiliary equipment associated with each PGM are grouped together as shown Figure A-16.

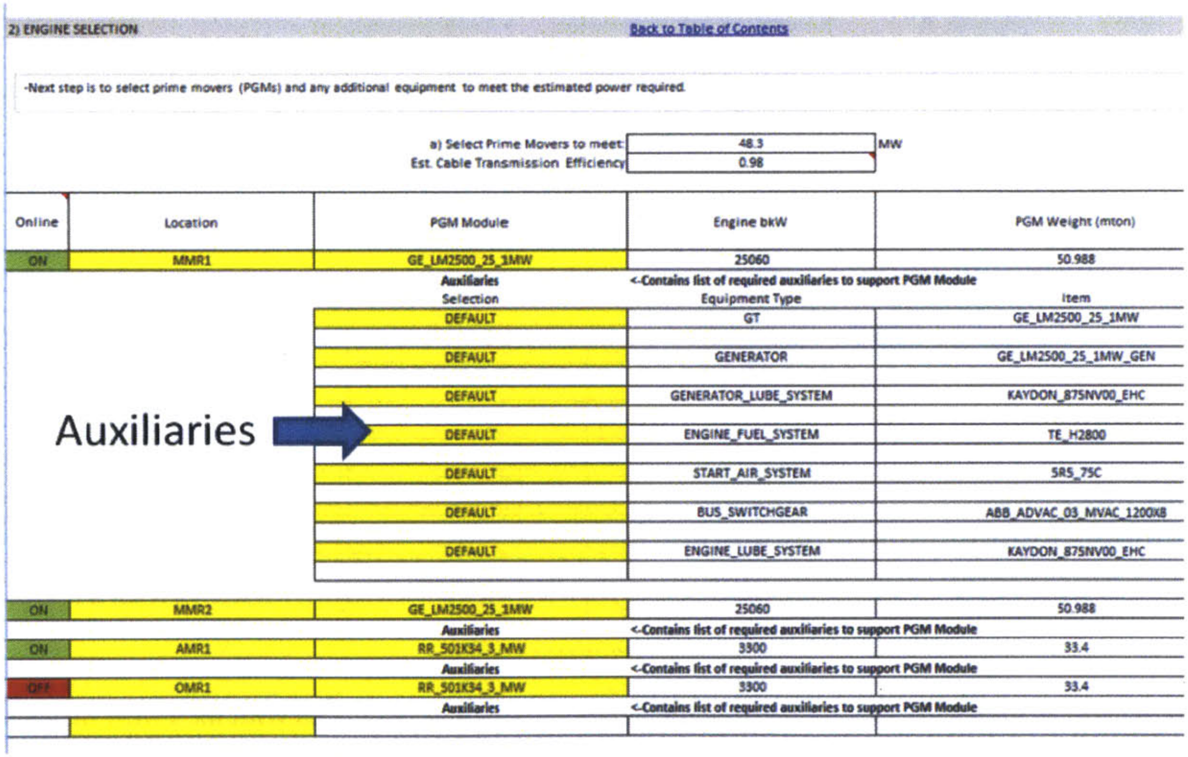


Figure A-16: Engine Selection

IPSDMv1.0 allows the user to override the default auxiliaries associated with the PGM database; however, it is recommended any permanent changes be made in the PGM database directly. To override individual default auxiliaries in the Input Sheet, the user can change the "DEFAULT" cell to "CUSTOM." Conditional Formatting within MS Excel actives the cells based on the selection. After making this selection, the user must click the Calculate button to initiate the change. Once the change is initiated the user can then modify the auxiliary data. For the purposes of this exercise, keep the default auxiliaries.

4. Expand Section 3) PROPULSION MOTOR MODULE SELECTION

The process for selecting the PMM is similar to the PGM selection process. For this design, PMMs were selected to meet the propulsion power requirement of 38 MW. For more information on PPF and the Compute option, see Chapter 3 Section 3.2.2. Select the following PMMs and associated compartments to satisfy the power and compartment requirements:

- MMR1>CONVERTEAM_IPS_AIM_19MW
- MMR2>CONVERTEAM_IPS_AIM_19MW

Figure A-17 is a result of the PMM selection.

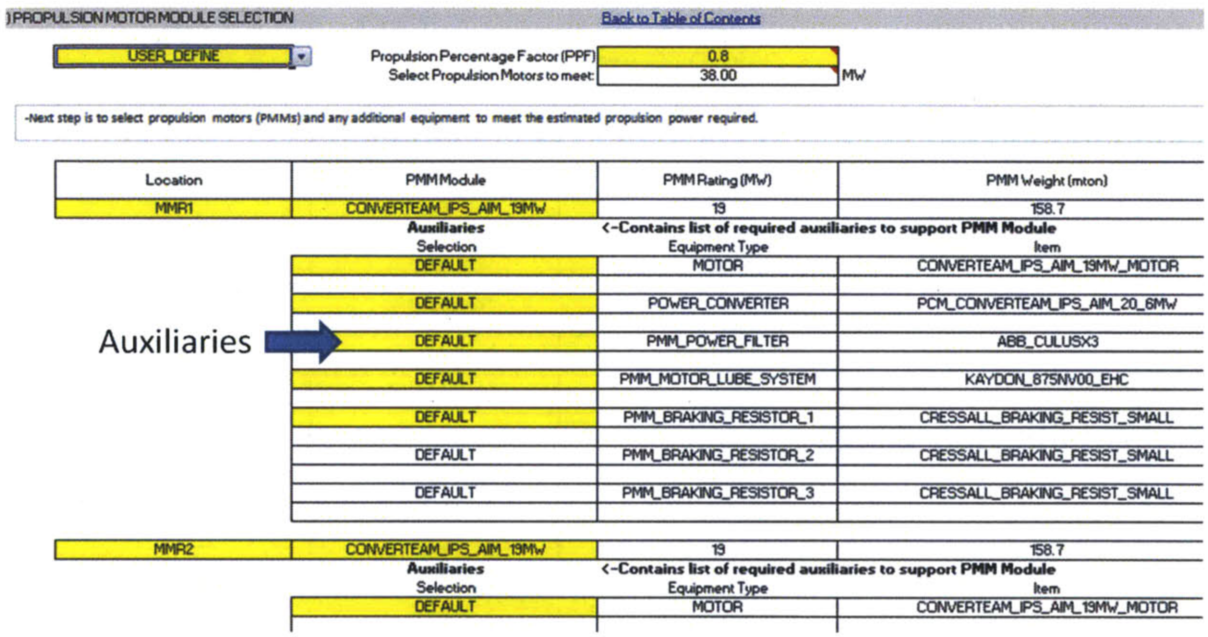


Figure A-17: PMM Selection

IPSDMv1.0 allows the user to override the default auxiliaries associated with the PMM database; however, it is recommended any permanent changes should be made in the PMM database directly. To override individual default auxiliaries in the Input Sheet, the user can change the "DEFAULT" cells to "CUSTOM." Conditional Formatting within MS Excel actives the cells based on the selection. After making this selection, the user must click the Calculate button to initiate the change. Once the change is initiated the user can then modify the auxiliary data. For the purposes of this exercise, keep the default auxiliaries.

5. Expand Section 4) ADDITIONAL COMPARTMENTS

This IPS design requires an additional compartment in the form of AMR2. See Chapter 3 Section 3.6.3 for the design philosophy behind the additional compartment. Select "Yes" to add AMR2. The result is shown in Figure A-18.

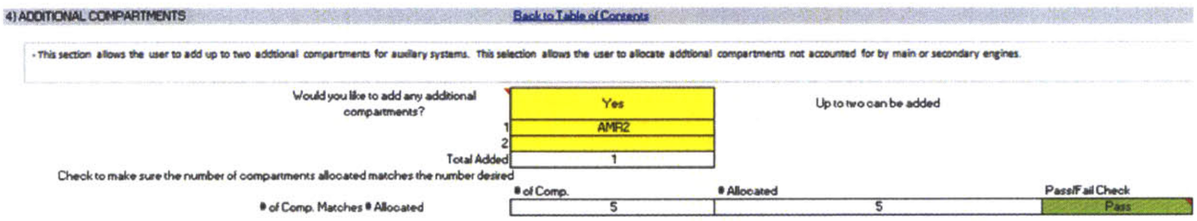


Figure A-18: Additional Compartments

The "# of Comp. Matches # Allocated" indicates if the PGM and PMM selections align with the compartment definitions in Section 1. This feature provides the user with a visual and numerical indicator if an error during the PGM and PMM selection took place.

6. Expand Section 5) AUXILIARY SELECTIONS

Section 5 allows the user to add additional auxiliaries that may be a function of the compartment need versus the equipment need. See Chapter 3 Section 3.2.3 for more information. Select "Yes" for each compartment to add sea water cooling and fire systems, and the following equipment items: AURORA_481__BASE_12_SW_PUMP and AURORA_481__BASE_12_FIRE_PUMP. The result is shown in Figure A-19.

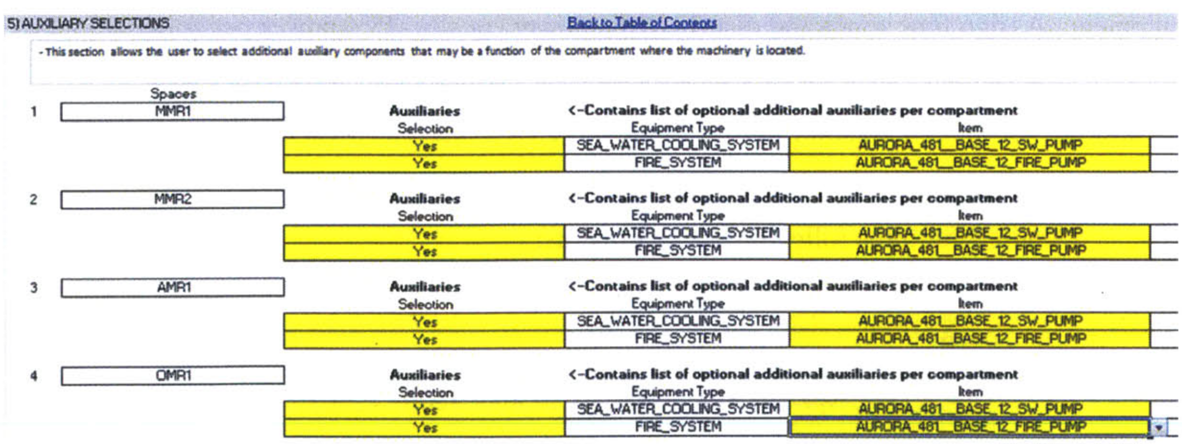


Figure A-19: Auxiliary Selections

Conditional Formatting within MS Excel actives the cells based on the selection.

7. Expand Section 6) ELECTRICAL LOAD ANALYSIS

For more information on the assumptions and procedure of the electrical load analysis see Chapter 3 Section 3.3. The result of the electrical load analysis is shown in Figure A-20.

Power Profile Summary

Go to Electrical Load Analysis

Power Profile	kW	Max load Design Indicator
Anchor	-197.1	
Shore	-150.4	
Cruising	-332.3	
Functional	-366.5	<--Design Condition
Emergency	-118.4	

Summary of Loads

Power Input/Outputs	MW
Total Installed Brake Power	53.4
Total Distributable Power	49.8
Total Required Propulsion Power	42.8
Total Auxiliary Power at Max Demand	-0.4

Net Power Available	6.6
Net Power SS Value Compared to SS Target:	2.55

Figure A-20: Electrical Load Analysis Summary

The Input Sheet only depicts the electrical analysis summary; however, should the user prefer to see the analysis, a hyperlink to the Electrical Load Analysis sheet is provided.

8. Expand Section 7) IPS SELECTIONS

For more information on the assumptions and procedure of the IPS Selection process see Chapter 3 Section 3.4. After the appropriate PGM, PMM, and auxiliary equipment were selected, an estimated maximum margined electrical load of 6.9 MW was determined available for distribution. The distribution for each port and starboard bus was estimated at 3.5 MW. This value coupled with the auxiliary electrical load will determine the power capacity of the PCM equipment. Assign four zones and distribute the power equally, 25% power per zone.

The desired distribution system for this design was a DC zonal electrical distribution system divided into four zones with power evenly distributed between each zone. Assign the zones and associated equipment to the following compartments:

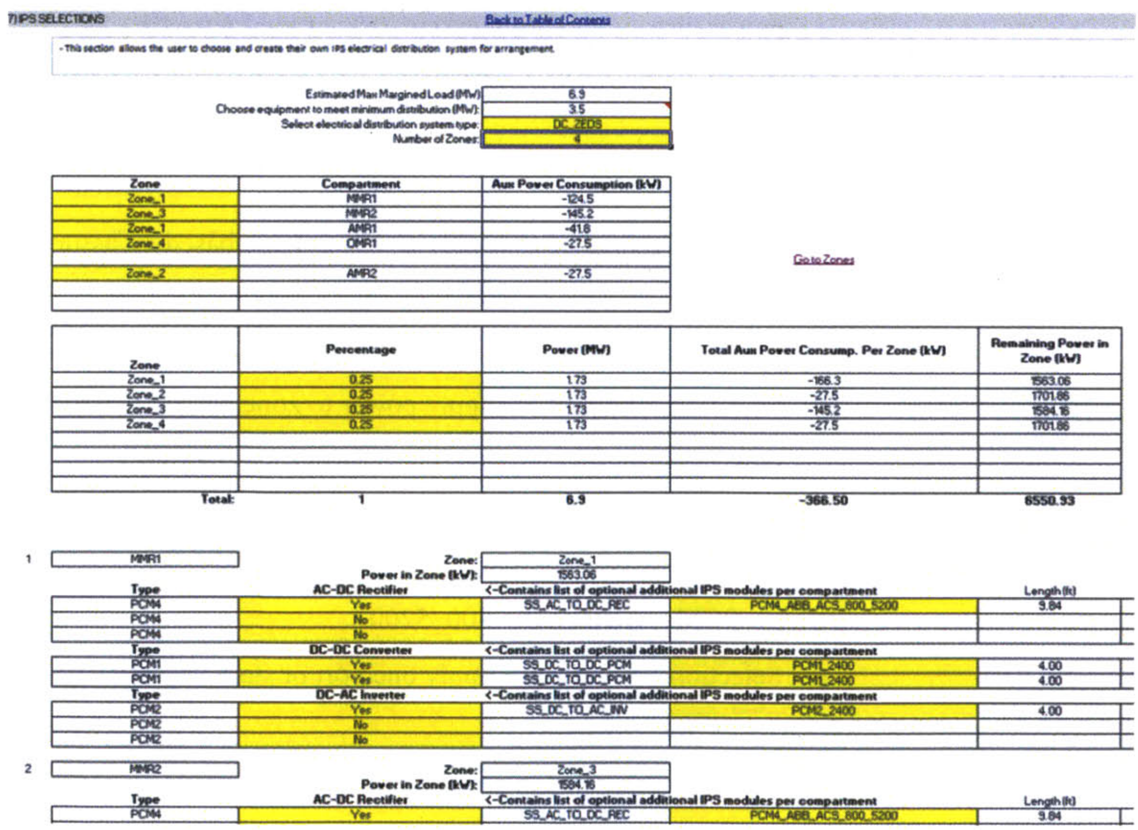
- Zone_1
  - AMR1
    - 1xPCM4> PCM4_ABB_ACS_800_5200
      - Selection estimated to supply one port or starboard bus
    - 2xPCM1> PCM1_2400

        - Selection estimated to supply power to zone based on assumed power distribution provide (i.e. 25% of total 6.9 MW)
    - 1xPCM2> PCM2_2400
        - Selection estimated to supply power to zone based on assumed power distribution provide (i.e. 25% of total 6.9 MW)
  - MMR1
    - 1xPCM4> PCM4_ABB_ACS_800_5200
        - Selection estimated to supply one port or starboard bus
    - 2xPCM1> PCM1_2400
        - Selection estimated to supply power to zone based on assumed power distribution provide (i.e. 25% of total 6.9 MW)
    - 1xPCM2> PCM2_2400
        - Selection estimated to supply power to zone based on assumed power distribution provide (i.e. 25% of total 6.9 MW)
- Zone_2
  - AMR2
    - 2xPCM1> PCM1_2400
        - Selection estimated to supply power to zone based on assumed power distribution provide (i.e. 25% of total 6.9 MW)
    - 1xPCM2> PCM2_2400
        - Selection estimated to supply power to zone based on assumed power distribution provide (i.e. 25% of total 6.9 MW)
- Zone_3
  - MMR2
    - 1xPCM4> PCM4_ABB_ACS_800_5200
        - Selection estimated to supply one port or starboard bus
    - 2xPCM1> PCM1_2400
        - Selection estimated to supply power to zone based on assumed power distribution provide (i.e. 25% of total 6.9 MW)
    - 1xPCM2> PCM2_2400

        - Selection estimated to supply power to zone based on assumed power distribution provide (i.e. 25% of total 6.9 MW)

- Zone_4
  - OMR1
    - 1xPCM4> PCM4_ABB_ACS_800_5200
      - Selection estimated to supply one port or starboard bus
    - 2xPCM1> PCM1_2400
      - Selection estimated to supply power to zone based on assumed power distribution provide (i.e. 25% of total 6.9 MW)
    - 1xPCM2> PCM2_2400
      - Selection estimated to supply power to zone based on assumed power distribution provide (i.e. 25% of total 6.9 MW)

The result of zonal selection is shown in Figure A-21.



7) IPS SELECTIONS Back to Table of Contents

- This section allows the user to choose and create their own IPS electrical distribution system for arrangement.

Estimated Max Margined Load (MW):	6.9
Choose equipment to meet minimum distribution (MW):	3.5
Select electrical distribution system type:	DC_ZEDS
Number of Zones:	4

Zone	Compartment	Aux Power Consumption (kW)
Zone_1	MMR1	-124.5
Zone_3	MMR2	-145.2
Zone_1	AMR1	-41.8
Zone_4	OMR1	-27.5
Zone_2	AMR2	-27.5

Go to Zones

Zone	Percentage	Power (MW)	Total Aux Power Consump. Per Zone (kW)	Remaining Power in Zone (kW)
Zone_1	0.25	1.73	-166.3	1563.06
Zone_2	0.25	1.73	-27.5	1701.86
Zone_3	0.25	1.73	-145.2	1584.16
Zone_4	0.25	1.73	-27.5	1701.86
Total:	1	6.9	-366.50	6550.93

1 MMR1 Zone: Zone_1

Power in Zone (kW): 1563.06

Type	AC-DC Rectifier	<-Contains list of optional additional IPS modules per compartment		Length (ft)
PCM4	Yes	SS_AC_TO_DC_REC	PCM4_ABB_ACS_800_5200	9.84
PCM4	No			
PCM4	No			
Type	**DC-DC Converter**	**<-Contains list of optional additional IPS modules per compartment**		
PCM1	Yes	SS_DC_TO_DC_PCM	PCM1_2400	4.00
PCM1	Yes	SS_DC_TO_DC_PCM	PCM1_2400	4.00
Type	**DC-AC Inverter**	**<-Contains list of optional additional IPS modules per compartment**		
PCM2	Yes	SS_DC_TO_AC_INV	PCM2_2400	4.00
PCM2	No			
PCM2	No			

2 MMR2 Zone: Zone_3

Power in Zone (kW): 1584.16

Type	AC-DC Rectifier	<-Contains list of optional additional IPS modules per compartment		Length (ft)
PCM4	Yes	SS_AC_TO_DC_REC	PCM4_ABB_ACS_800_5200	9.84

Figure A-21: IPS Selection

Conditional Formatting within MS Excel actives the cells based on the selection. The electrical load analysis is not updated within IPSDMv1.0 after the selection of IPS equipment is completed. Further research must be conducted to increase the fidelity of the electrical distribution system as identified in Chapter 5 Section 5.1.

9. Expand Section 8) SELECTION SUMMARY

The Selection Summary lists the equipment for each compartment. The depiction of the equipment allows the user to view the equipment allocated to each compartment before beginning the arrangement process. Selecting the compartment from the dropdown menu and clicking the Calculate button will update the table to show the equipment list. The result of equipment selection summary for MMR2 is shown in Figure A-22.

8) SELECTION SUMMARY   Back to Table of Contents

- This section allows the user view a summary their equipment choices made in the sections above by compartment

SPACE: MMR2

#	Equipment Type	Item	Length (ft)	
1	GT	GE_LM2500_25_1MW	27.00131238	
2	GENERATOR	GE_LM2500_25_1MW_GEN	18.93044622	
3	GENERATOR_LUBE_SYSTEM	KAYDON_875NV00_EHC	2.95275591	
4	ENGINE_FUEL_SYSTEM	TE_H2800	13.1233596	
5	START_AIR_SYSTEM	5R5_75C	4.26509187	
6	BUS_SWITCHGEAR	ABB_ADVAC_03_MVAC_1200X8	18.37270344	
7	ENGINE_LUBE_SYSTEM	KAYDON_875NV00_EHC	2.95275591	
8	MOTOR	CONVERTEAM_IPS_AIM_19MW_MOTOR	14.27165357	
9	POWER_CONVERTER	PCM_CONVERTEAM_IPS_AIM_20_6MW	15.74803152	
10	PMM_POWER_FILTER	ABB_CULUSX3	13.77952758	
11	PMM_MOTOR_LUBE_SYSTEM	KAYDON_875NV00_EHC	2.95275591	
12	PMM_BRAKING_RESISTOR_1	CRESSALL_BRAKING_RESIST_SMALL	5.57742783	
13	PMM_BRAKING_RESISTOR_2	CRESSALL_BRAKING_RESIST_SMALL	5.57742783	
14	PMM_BRAKING_RESISTOR_3	CRESSALL_BRAKING_RESIST_SMALL	5.57742783	
15	SEA_WATER_COOLING_SYSTEM	AURORA_481__BASE_12_SW_PUMP	4.59317586	
16	FIRE_SYSTEM	AURORA_481__BASE_12_FIRE_PUMP	4.59317586	
17	SS_AC_TO_DC_REC	PCM4_ABB_ACS_800_5200	9.8425197	
18	SS_DC_TO_DC_PCM	PCM1_2400	4.002624678	
19	SS_DC_TO_DC_PCM	PCM1_2400	4.002624678	
20	SS_DC_TO_AC_INV	PCM2_2400	4.002624678	
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				

Figure A-22: Selection Summary

10. Expand Section 9) COOLING LOAD ANALYSIS SUMMARY

For more information on the assumptions and procedure of the thermal load analysis see Chapter 3 Section 3.5. The result of the thermal load analysis is shown in Figure A-23.

Cooling Profile Summary Go to Thermal Load Analysis

Cooling Profile	kW	Max load Design Indicator
Anchor	1070.343124	
Shore	1067.074124	
Cruising	4030.25031	
Functional	5089.190433	<--Design Condition
Emergency	2121.380248	

Estimated Maximum Cooling Required (MW)	5.089190433

Figure A-23: Cooling Load Analysis Summary

The Input Sheet only depicts the thermal load analysis summary; however, should the user prefer to see the analysis, a hyperlink to the Cooling Load Analysis sheet is provided.

11. Expand Section 10) DECK HEIGHT DEFINITION

After all of the equipment selections are made, deck heights can be estimated. The estimated maximum number of decks for this design is four. Enter "4" into the "Select # of MMR Decks" cell and the following deck heights:

- height of MMR lowest Deck = 4 ft
- height of MMR 2nd lowest Deck = 13.5 ft
- height of MMR 3nd lowest Deck = 24.5 ft
- height of MMR 4th lowest Deck =34.5 ft

12. Expand Section 11) COMPARTMENT ARRANGEMENT DIAGRAM SUMMARY

This section summarizes the equipment arrangement in each compartment. The user must locate each compartment sheet to manually arrange the equipment. Hyperlinks to each compartment are provided in IPSDMv1.0.

The arrangement of equipment takes place within Compartment Sheets 1-8. Data is entered into the yellow cells via dropdown selections and direct entry. The PGM, PMM, and auxiliary equipment assigned in Sections 2, 3, 4, 5, and 7 appear in the compartment sheets. Each sheet contains the following format depicted in Figure A-24.

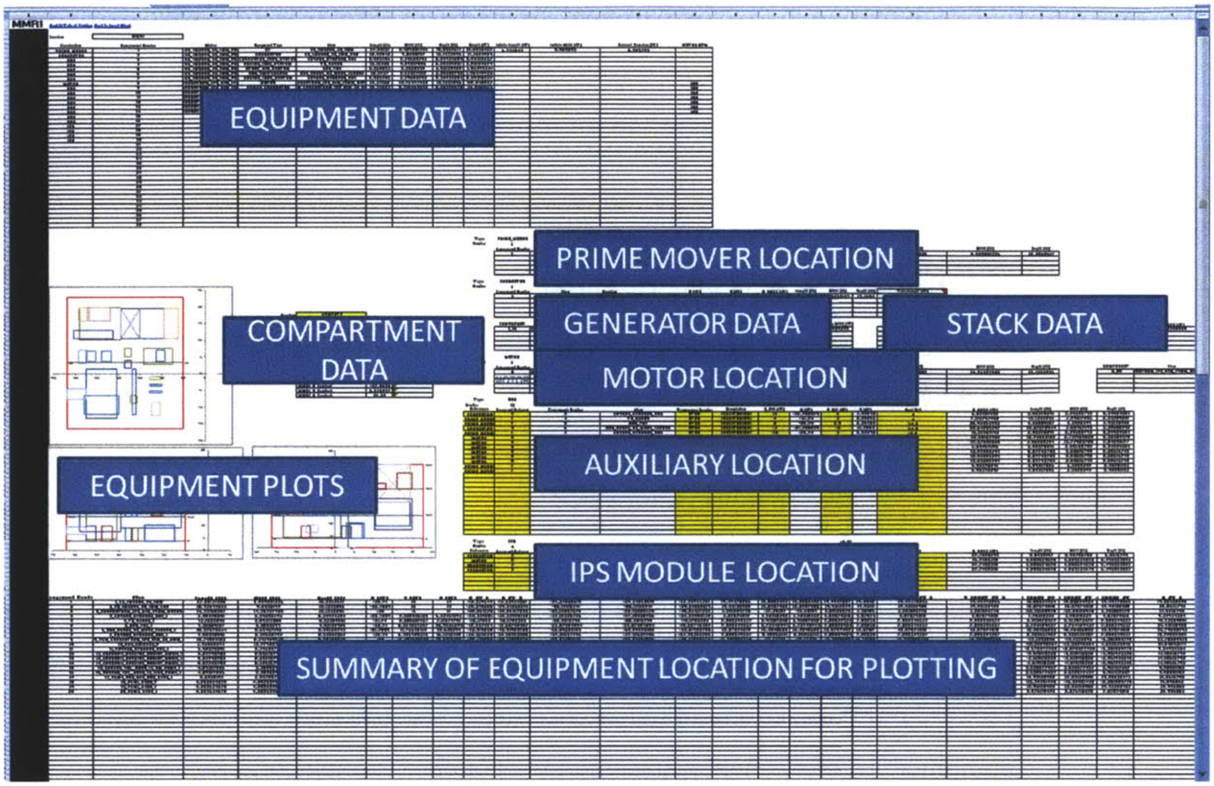


Figure A-24: Compartment Sheet

The axis convention for arrangement is shown in Figure A-25.

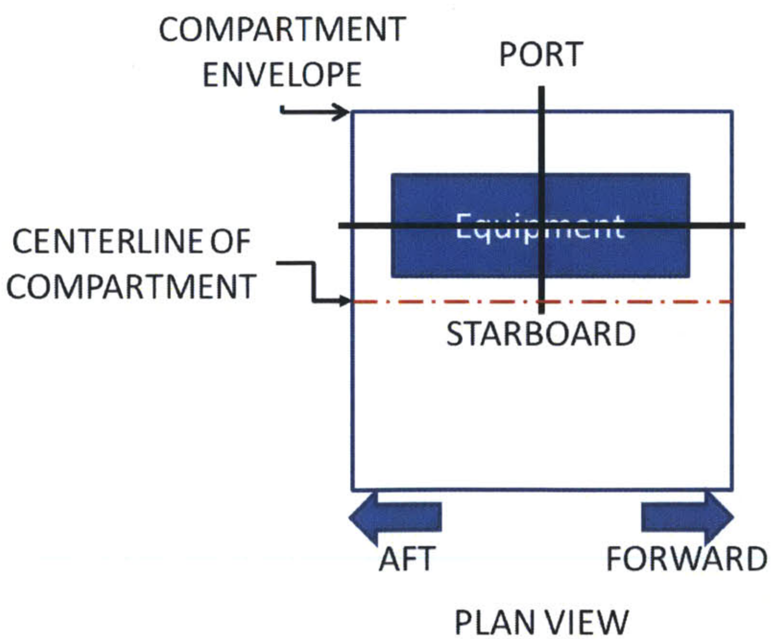


Figure A-25: Axis Convention

The description of each section in the compartment arrangement sheet is as follows:

- Equipment Data
    - Summary of equipment selected for the compartment. Includes dimensions, weight, name, and categories.
- Prime Mover Location
    - If a prime mover from a PGM is present, then the user must locate the prime mover in x, y, and z Cartesian space. The prime mover can act as an equipment reference when arranging the auxiliary equipment.
    - If more than one prime mover is present, then the follow-on prime movers will be referenced to the first prime mover.
- Generator Data
    - If a prime mover is present with its associated generator, it appears in this section. The user can orient the generator and corresponding prime mover in either the forward or aft direction but not athwartship. The generator can act as an equipment reference when arranging the auxiliary equipment.
    - If more than one generator is present, then the follow-on generators will appear.
- Stack Data
    - If prime movers are present, then intakes and exhaust stacks are present. The default stack positions are at the forward and aft extents of the prime mover module. The user can adjust the position of the stacks in the x-direction only if the stacks are located in an alternate location of the prime mover module.
- Motor Location
    - If a motor from a PMM is present, then the user must locate the motor in x, y, and z Cartesian space. The motor can act as an equipment reference when arranging the auxiliary equipment.
    - If more than one motor is present, then the follow-on motors will be referenced to the first motor.
    - The user can enter data related to the shafting to the right of motor section. The user can enter the following data:
        - Shaft diameter

- Direction of shaft and motor (reserved for podded propulsion). Default direction is aft.
- Method
    - Compute: automatically terminates the shaft to the extent of the compartment
    - User_Define: allows the user to specify a shaft distance (reserved for podded propulsion)
- Length
    - If User_Define is selected, then the user must enter a length
- Z_add
    - Allows the user to adjust the vertical location of the shaft on the motor. Default vertical position is at the center of the motor.

- Auxiliary Location
    - Locate auxiliary equipment for PGM(s), PMM(s), and compartment.
    - Must choose a Prime Mover, Generator, or Motor reference.
    - Must choose transverse location relative to equipment reference and orientation in the longitudinal or transverse direction.
    - The equipment is placed around the Prime Mover, Generator, or Motor reference. Factors in the x-direction and y-direction guide the user in equipment arrangement. Figure A-26 depicts an example of the reference and factor usage.

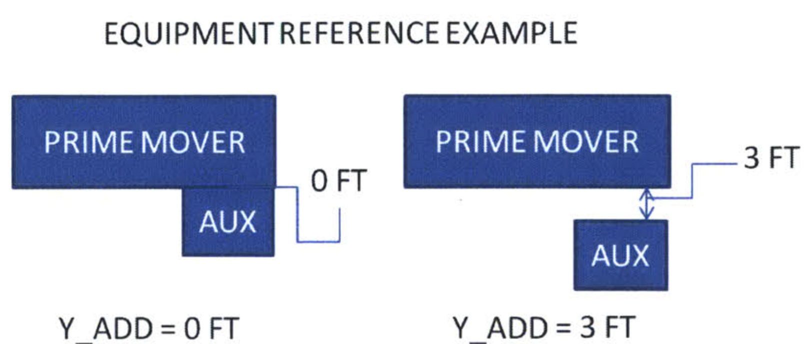


Figure A-26: Equipment Reference Example

- The user can also select the centerline as an option. The centerline option does not require an equipment reference, but rather references the centerline of the compartment. However, caution should be exercised when using this function due to the increased computational time required to execute the command. The centerline calculation is an iterative calculation process within IPSDMv1.0.

  - The user must select a corresponding deck reference to locate the auxiliary equipment in the vertical direction. The deck reference can be overwritten for a particular piece of equipment simply by entering in a desired deck height in the deck reference location.

- IPS Module Location
  - The same principles in auxiliary arrangement apply the IPS equipment.
  - Must choose a Prime Mover, Generator, or Motor reference.
  - Must choose transverse location relative to equipment reference and orientation in the longitudinal or transverse direction.
  - The equipment is placed around the Prime Mover, Generator, or Motor reference. Factors in the x-direction and y-direction guide the user in equipment arrangement.
  - The user can also select the centerline as an option. The centerline option does not require an equipment reference, but rather references the centerline of the compartment. However, caution should be exercised when using this function due to the increased computational time required to execute the command.
  - The user must select a corresponding deck reference to locate the auxiliary equipment in the vertical direction. The deck reference can be overwritten for a particular piece of equipment simply by entering in a desired deck height in the deck reference location.
- Summary of Equipment Location for Plotting
  - The data presented in this section is a result of the user arrangement inputs.
- Equipment Plots
  - The data is plotted to graphically show the position of equipment in the compartment.
  - The user can select the equipment in the plot for identification simply by clicking on the equipment in the plot.
  - If an error in the data entry was made such as an incorrect reference, the plot will indicate the error in as shown in Figure A-27.

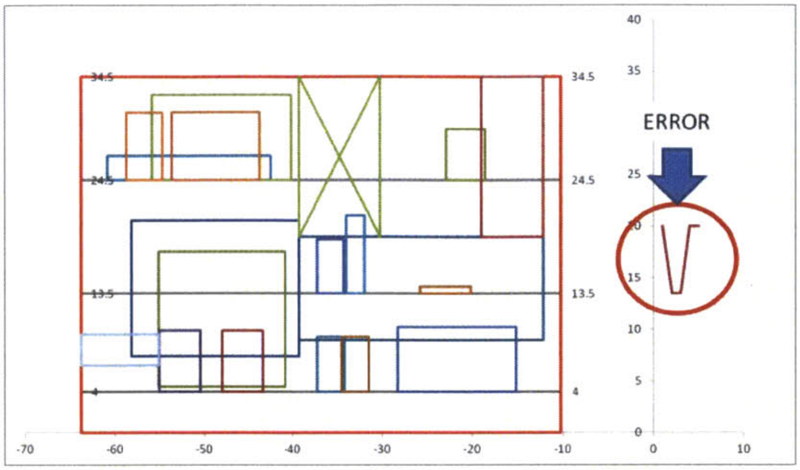


Figure A-27: Error Depiction

- Compartment Data
  - Overall compartment data is computed based on equipment arrangement. The following data is computed:
    - Minimum compartment length coordinate
    - Maximum compartment length coordinate
    - Minimum compartment width coordinate
    - Maximum compartment width coordinate
    - Minimum compartment height coordinate
    - Maximum compartment height coordinate
    - Centerline position
    - Overall length
    - Overall width
    - Overall height
    - X-centroid
    - Y-centroid
    - Z-centroid
  - The user also has the option of adding factors to the minimum compartment length coordinate, maximum compartment length coordinate, minimum compartment width coordinate, and maximum compartment width coordinate. These factors increase the overall size of the compartment to account for access around the outermost equipment.

- The user also can override the computation of the compartment to provide a user defined size. Overriding the computation also allows the user to size the null compartments, compartments without a PGM or PMM present.

13. Locate Compartment 1 Sheet: MMR1

The following list of equipment should appear in Compartment Sheet 1 for MMR1:

Equipment Type	Item
GT	GE_LM2500_25_1MW
GENERATOR	GE_LM2500_25_1MW_GEN
GENERATOR_LUBE_SYSTEM	KAYDON_875NV00_EHC
ENGINE_FUEL_SYSTEM	TE_H2800
START_AIR_SYSTEM	5R5_75C
BUS_SWITCHGEAR	ABB_ADVAC_03_MVAC_1200X8
ENGINE_LUBE_SYSTEM	KAYDON_875NV00_EHC
MOTOR	CONVERTEAM_IPS_AIM_19MW_MOTOR
POWER_CONVERTER	PCM_CONVERTEAM_IPS_AIM_20_6MW
PMM_POWER_FILTER	ABB_CULUSX3
PMM_MOTOR_LUBE_SYSTEM	KAYDON_875NV00_EHC
PMM_BRAKING_RESISTOR_1	CRESSALL_BRAKING_RESIST_SMALL
PMM_BRAKING_RESISTOR_2	CRESSALL_BRAKING_RESIST_SMALL
PMM_BRAKING_RESISTOR_3	CRESSALL_BRAKING_RESIST_SMALL
SEA_WATER_COOLING_SYSTEM	AURORA_481__BASE_12_SW_PUMP
FIRE_SYSTEM	AURORA_481__BASE_12_FIRE_PUMP
SS_AC_TO_DC_REC	PCM4_ABB_ACS_800_5200
SS_DC_TO_DC_PCM	PCM1_2400
SS_DC_TO_DC_PCM	PCM1_2400
SS_DC_TO_AC_INV	PCM2_2400

The list above was generated based on the equipment selections made earlier in the tutorial. Following the compartment sheet description of Section 12, input the following data into the yellow cells only:

PRIME_MOVER

Component Number	Item	Orientation	X (FT)	Y (FT)	Z_Add (FT)
1	GE_LM2500_25_1MW	PORT	-25.74	15	14

GENERATOR

Component Number	Item	Direction
2	GE_LM2500_25_1MW_GEN	AFT

INTAKE AND EXHAUST

Component Number	Item	X_Add (FT)
1_IN	GE_LM2500_25_1MW_INTAKE_PD	0

Component Number	Item	X_Add (FT)
1_EX	GE_LM2500_25_1MW_EXHAUST_PD	0

MOTOR

Component Number	Item	Orientation	X (FT)	Y (FT)	Z_Add (FT)
8	CONVERTEAM_IPS_AIM_19MW_MOTOR	STBD	-48	-6	11

SHAFT

Component Number	Item	Shaft Diameter (ft)	Direction	Method	LENGTH (ft)	Z_Add (ft)
8_SH	CONVERTEAM_IPS_AIM_19MW_MOTOR_SHAFT	3	AFT	COMPUTE	0	-3

AUX

Reference	Equipment Reference	Component Number	Item	Transverse	Orientation	X_Add (FT)	Y_Add (FT)	Deck Ref
GENERATOR	2	3	KAYDON_875NV00_EHC	STBD	LONGITUDINAL	13	6	4
PRIME_MOVER	1	4	TE_H2800	STBD	LONGITUDINAL	4	3	4
PRIME_MOVER	1	5	5R5_75C	STBD	LONGITUDINAL	5	3.5	24.5
GENERATOR	2	6	ABB_ADVAC_03_MVAC_1200X8	STBD	LONGITUDINAL	-3	-3	24.5
PRIME_MOVER	1	7	KAYDON_875NV00_EHC	STBD	LONGITUDINAL	-10	3	13.5
MOTOR	8	9	PCM_CONVERTEAM_IPS_AIM_20_6MW	STBD	LONGITUDINAL	0	-7	24.5
MOTOR	8	10	ABB_CULUSX3	STBD	TRANSVERSE	15	-9	13.5
MOTOR	8	11	KAYDON_875NV00_EHC	STBD	LONGITUDINAL	15	-7	4
MOTOR	8	12	CRESSALL_BRAKING_RESIST_SMALL	PORT	LONGITUDINAL	25	-7	13.5
MOTOR	8	13	CRESSALL_BRAKING_RESIST_SMALL	PORT	LONGITUDINAL	25	-5	13.5
MOTOR	8	14	CRESSALL_BRAKING_RESIST_SMALL	PORT	LONGITUDINAL	25	-3	13.5
PRIME_MOVER	1	15	AURORA_481__BASE_12_SW_PUMP	CL	LONGITUDINAL	-20	2	4
PRIME_MOVER	1	16	AURORA_481__BASE_12_FIRE_PUMP	CL	LONGITUDINAL	-27	2	4

IPS

Reference	Equipment Reference	Component Number	Item	Transverse	Orientation	X_Add (FT)	Y_Add (FT)	Deck Ref
GENERATOR	2	17	PCM4_ABB_ACS_800_5200	PORT	LONGITUDINAL	0	-4	24.5
MOTOR	8	18	PCM1_2400	STBD	TRANSVERSE	25	-5	13.5
GENERATOR	2	19	PCM1_2400	PORT	LONGITUDINAL	-8	-4	24.5
GENERATOR	2	20	PCM2_2400	STBD	LONGITUDINAL	-8	3	24.5

COMPARTMENT DATA

Selection	COMPUTE
Addition	**Parameter**
2	MMR1_Length_Min
-3	MMR1_Length_Max
-3	MMR1_Width_Min
3	MMR1_Width_Max

Once the data entry is complete, click the Calculate button at the bottom left of the worksheet to lock-in the values. The result of the data entry should look like Figure A-28.

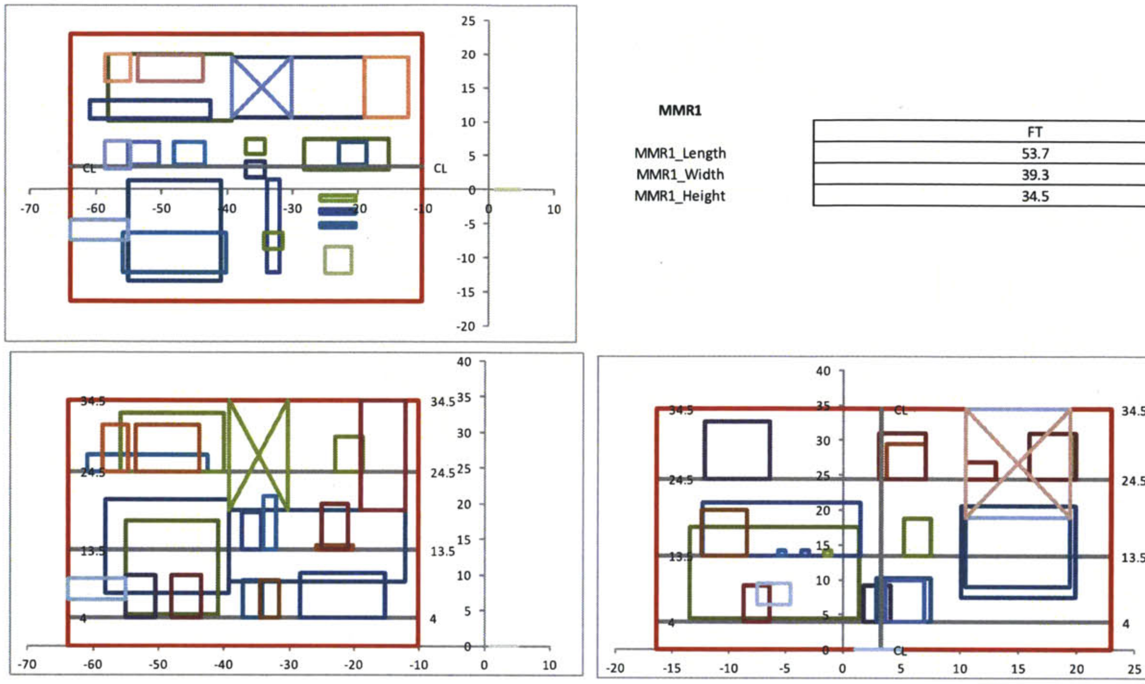


Figure A-28: MMR1 Tutorial Arrangement

The same procedure is conducted for the next compartment after the arrangement is satisfied.

14. Locate Compartment 2 Sheet: MMR2

The following list of equipment should appear in Compartment Sheet 2 for MMR2:

Equipment Type	Item
GT	GE_LM2500_25_1MW
GENERATOR	GE_LM2500_25_1MW_GEN
GENERATOR_LUBE_SYSTEM	KAYDON_875NV00_EHC
ENGINE_FUEL_SYSTEM	TE_H2800
START_AIR_SYSTEM	5R5_75C
BUS_SWITCHGEAR	ABB_ADVAC_03_MVAC_1200X8
ENGINE_LUBE_SYSTEM	KAYDON_875NV00_EHC
MOTOR	CONVERTEAM_IPS_AIM_19MW_MOTOR
POWER_CONVERTER	PCM_CONVERTEAM_IPS_AIM_20_6MW
PMM_POWER_FILTER	ABB_CULUSX3
PMM_MOTOR_LUBE_SYSTEM	KAYDON_875NV00_EHC
PMM_BRAKING_RESISTOR_1	CRESSALL_BRAKING_RESIST_SMALL
PMM_BRAKING_RESISTOR_2	CRESSALL_BRAKING_RESIST_SMALL
PMM_BRAKING_RESISTOR_3	CRESSALL_BRAKING_RESIST_SMALL
SEA_WATER_COOLING_SYSTEM	AURORA_481__BASE_12_SW_PUMP
FIRE_SYSTEM	AURORA_481__BASE_12_FIRE_PUMP

SS_AC_TO_DC_REC	PCM4_ABB_ACS_800_5200
SS_DC_TO_DC_PCM	PCM1_2400
SS_DC_TO_DC_PCM	PCM1_2400
SS_DC_TO_AC_INV	PCM2_2400

The list above was generated based on the equipment selections made earlier in the tutorial. Following the compartment sheet description of Section 12, input the following data into the yellow cells only:

PRIME_MOVER

Component Number	Item	Orientation	X (FT)	Y (FT)	Z_Add (FT)
1	GE_LM2500_25_1MW	STBD	-35	-15	16

GENERATOR

Component Number	Item	Direction
2	GE_LM2500_25_1MW_GEN	FWD

INTAKE AND EXHAUST

Component Number	Item	X_Add (FT)
1_IN	GE_LM2500_25_1MW_INTAKE_PD	0

Component Number	Item	X_Add (FT)
1_EX	GE_LM2500_25_1MW_EXHAUST_PD	0

MOTOR

Component Number	Item	Orientation	X (FT)	Y (FT)	Z_Add (FT)
8	CONVERTEAM_IPS_AIM_19MW_MOTOR	STBD	-11	6	11

SHAFT

Component Number	Item	Shaft Diameter (ft)	Direction	Method	LENGTH (ft)	Z_Add (ft)
8_SH	CONVERTEAM_IPS_AIM_19MW_MOTOR_SHAFT	3	AFT	COMPUTE	0	-3

AUX

Reference	Equipment Reference	Component Number	Item	Transverse	Orientation	X_Add (FT)	Y_Add (FT)	Deck Ref
GENERATOR	2	3	KAYDON_875NV00_EHC	PORT	LONGITUDINAL	-13	6	4
PRIME_MOVER	1	4	TE_H2800	PORT	LONGITUDINAL	-4	3	4
PRIME_MOVER	1	5	5R5_75C	PORT	LONGITUDINAL	-5	3.5	24.5
GENERATOR	2	6	ABB_ADVAC_03_MVAC_1200X8	PORT	LONGITUDINAL	3	-3	24.5
PRIME_MOVER	1	7	KAYDON_875NV00_EHC	PORT	LONGITUDINAL	10	3	13.5
MOTOR	8	9	PCM_CONVERTEAM_IPS_AIM_20_6MW	PORT	LONGITUDINAL	0	-7	24.5
MOTOR	8	10	ABB_CULUSX3	PORT	TRANSVERSE	-15	-9	13.5
MOTOR	8	11	KAYDON_875NV00_EHC	PORT	LONGITUDINAL	-15	-7	4
MOTOR	8	12	CRESSALL_BRAKING_RESIST_SMALL	STBD	LONGITUDINAL	-25	-7	13.5
MOTOR	8	13	CRESSALL_BRAKING_RESIST_SMALL	STBD	LONGITUDINAL	-25	-5	13.5
MOTOR	8	14	CRESSALL_BRAKING_RESIST_SMALL	STBD	LONGITUDINAL	-25	-3	13.5
PRIME_MOVER	1	15	AURORA_481__BASE_12_SW_PUMP	CL	LONGITUDINAL	20	-2	4
PRIME_MOVER	1	16	AURORA_481__BASE_12_FIRE_PUMP	CL	LONGITUDINAL	27	-2	4

IPS

Reference	Equipment Reference	Component Number	Item	Transverse	Orientation	X_Add (FT)	Y_Add (FT)	Deck Ref
GENERATOR	2	17	PCM4_ABB_ACS_800_5200	STBD	LONGITUDINAL	0	-4	24.5
MOTOR	8	18	PCM1_2400	PORT	TRANSVERSE	-25	-5	13.5
GENERATOR	2	19	PCM1_2400	STBD	LONGITUDINAL	8	-4	24.5
GENERATOR	2	20	PCM2_2400	PORT	LONGITUDINAL	8	3	24.5

COMPARTMENT DATA

Selection	COMPUTE
Addition	Parameter
3	MMR2_Length_Min
-2	MMR2_Length_Max
-3	MMR2_Width_Min
3	MMR2_Width_Max

Note that the transverse position of the motor and prime mover are reversed as compared to MMR1. It is important to note on position of the motors, especially if they are in separate compartments, because the position will allow for the estimation of the propeller diameter. If two motors are present within the design, they must be spaced equally from the centerline of the ship.

Once the data entry is complete, click the Calculate button at the bottom left of the worksheet to lock-in the values. The result of the data entry should look like Figure A-29.

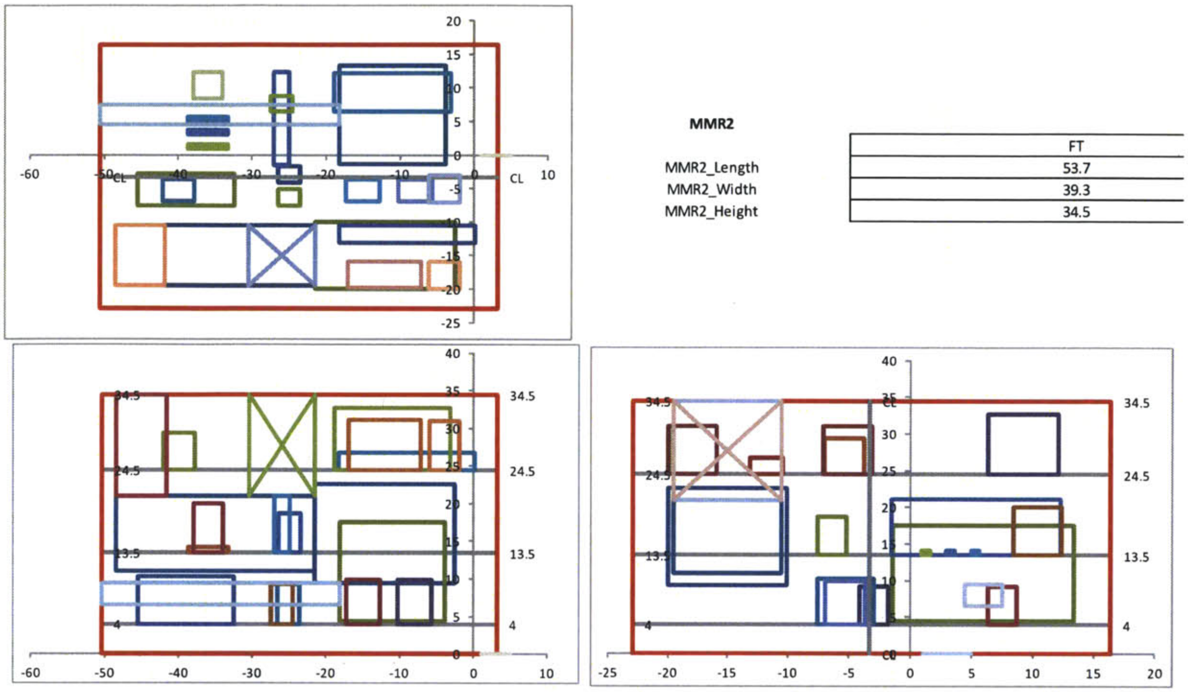


Figure A-29: MMR2 Tutorial Arrangement

The same procedure is conducted for the next compartment after the arrangement is satisfied.

15. Locate Compartment 3 Sheet: AMR1

The following list of equipment should appear in Compartment Sheet 3 for AMR1:

Equipment Type	Item
GT	RR_501K34_3_MW
GENERATOR	RR_501K34_3_MW_GEN
ENGINE_FUEL_SYSTEM	TE_H800
START_AIR_SYSTEM	5R5_75B
BUS_SWITCHGEAR	ABB_MAXSG
SEA_WATER_COOLING_SYSTEM	AURORA_481__BASE_12_SW_PUMP
FIRE_SYSTEM	AURORA_481__BASE_12_FIRE_PUMP
SS_AC_TO_DC_REC	PCM4_ABB_ACS_800_5200
SS_DC_TO_DC_PCM	PCM1_2400
SS_DC_TO_DC_PCM	PCM1_2400
SS_DC_TO_AC_INV	PCM2_2400

The list above was generated based on the equipment selections made earlier in the tutorial. Following the compartment sheet description of Section 12, input the following data into the yellow cells only:

PRIME_MOVER

Component Number	Item	Orientation	X (FT)	Y (FT)	Z_Add (FT)
1	RR_501K34_3_MW	PORT	-25.74	0	9

GENERATOR

Component Number	Item	Direction
2	RR_501K34_3_MW_GEN	FWD

INTAKE AND EXHAUST

Component Number	Item	X_Add (FT)
1_IN	RR_501K34_3_MW_INTAKE_SS	4

Component Number	Item	X_Add (FT)
1_EX	RR_501K34_3_MW_EXHAUST_SS	-19

AUX

Reference	Equipment Reference	Component Number	Item	Transverse	Orientation	X_Add (FT)	Y_Add (FT)	Deck Ref
PRIME_MOVER	1	3	TE_H800	PORT	LONGITUDINAL	-6	2.5	4
PRIME_MOVER	1	4	5R5_75B	PORT	LONGITUDINAL	-9	3	13.5
GENERATOR	2	5	ABB_MAXSG	PORT	LONGITUDINAL	-8	3	13.5
GENERATOR	2	6	AURORA_481__BASE_12_SW_PUMP	PORT	LONGITUDINAL	-5	2.5	4
GENERATOR	2	7	AURORA_481__BASE_12_FIRE_PUMP	PORT	TRANSVERSE	0	2.5	4

IPS

Reference	Equipment Reference	Component Number	Item	Transverse	Orientation	X_Add (FT)	Y_Add (FT)	Deck Ref
GENERATOR	2	8	PCM4_ABB_ACS_800_5200	STBD	LONGITUDINAL	-5	3	13.5
GENERATOR	2	9	PCM1_2400	STBD	LONGITUDINAL	3	3	13.5
PRIME_MOVER	1	10	PCM1_2400	PORT	LONGITUDINAL	-6	4	24.5
PRIME_MOVER	1	11	PCM2_2400	STBD	LONGITUDINAL	-8	2.5	13.5

COMPARTMENT DATA

Selection: USER_DEFINE

Addition	Parameter	User Defined (FT)
3	AMR1_Length_Min	-3.549055094
-2	AMR1_Length_Max	-41.17892889
-2	AMR1_Width_Min	-12.90682416
6	AMR1_Width_Max	18.48162731
	AMR1_Height_Min	0
	AMR1_Height_Max	24.5

AMR1_Length	37.6298738
AMR1_Width	31.38845147
AMR1_X_Centroid	-22.36399199
AMR1_Y_Centroid	2.787401576
AMR1_Z_Centroid	12.25

Note that the Compartment Data is user defined. The user defined data allows the user to adjust the size of the compartment. AMR1_Width_Max is also offset with a value of 6. Offsetting the value allows the user to adjust the centerline position of the compartment. This adjustment allows for the prime mover or motor to be positioned off the centerline of the ship.

Much of the user defined data is copied from the Computed data, but not maximum height. Maximum height was changed because the extra deck above the space was not required for machinery. Changing this value does not hinder the user from placing equipment above the space as well. A PCM 1 was placed above the space to anticipate the upper service highway connection for the port bus.

Once the data entry is complete, click the Calculate button at the bottom left of the worksheet to lock-in the values. The result of the data entry should look like Figure A-30.

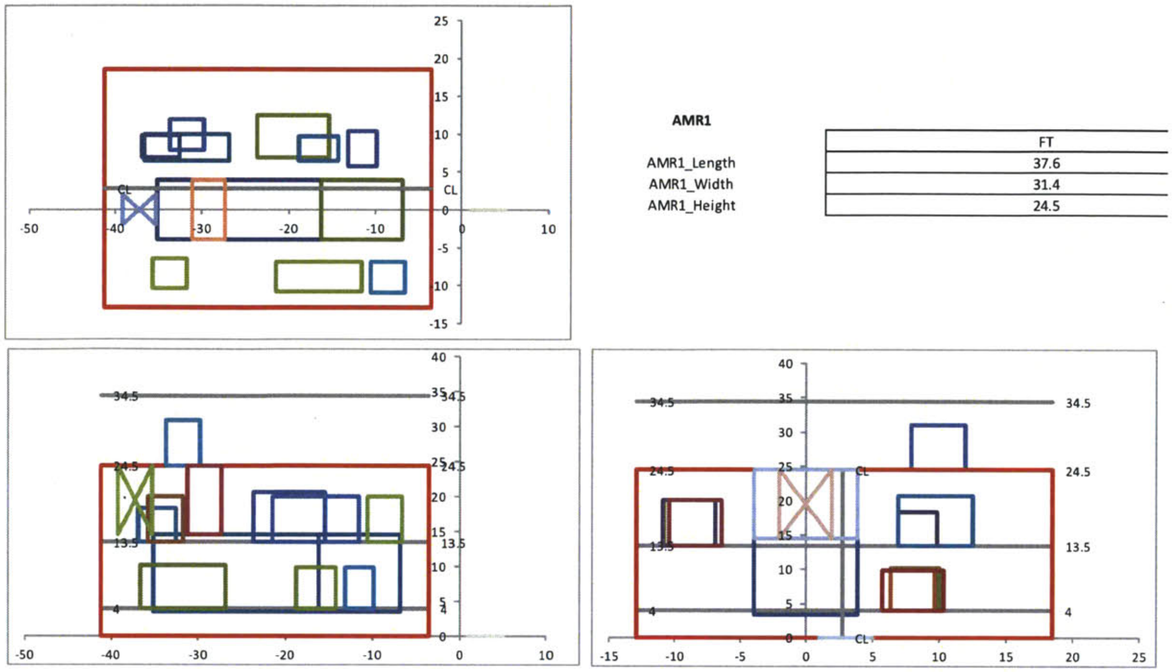


Figure A-30: AMR1 Tutorial Arrangement

The same procedure is conducted for the next compartment after the arrangement is satisfied.

16. Locate Compartment 4 Sheet: OMR1

The following list of equipment should appear in Compartment Sheet 4 for OMR1:

Equipment Type	Item
GT	RR_501K34_3_MW
GENERATOR	RR_501K34_3_MW_GEN
ENGINE_FUEL_SYSTEM	TE_H800
START_AIR_SYSTEM	5R5_75B
BUS_SWITCHGEAR	ABB_MAXSG
SEA_WATER_COOLING_SYSTEM	AURORA_481__BASE_12_SW_PUMP
FIRE_SYSTEM	AURORA_481__BASE_12_FIRE_PUMP
SS_AC_TO_DC_REC	PCM4_ABB_ACS_800_5200
SS_DC_TO_DC_PCM	PCM1_2400
SS_DC_TO_DC_PCM	PCM1_2400
SS_DC_TO_AC_INV	PCM2_2400

The list above was generated based on the equipment selections made earlier in the tutorial. Following the compartment sheet description of Section 12, input the following data into the yellow cells only:

PRIME_MOVER

Component Number	Item	Orientation	X (FT)	Y (FT)	Z_Add (FT)
1	RR_501K34_3_MW	PORT	-25.74	0	6

GENERATOR

Component Number	Item	Direction
2	RR_501K34_3_MW_GEN	AFT

INTAKE AND EXHAUST

Component Number	Item	X_Add (FT)
1_IN	RR_501K34_3_MW_INTAKE_SS	-3.55

Component Number	Item	X_Add (FT)
1_EX	RR_501K34_3_MW_EXHAUST_SS	9.5

AUX

Reference	Equipment Reference	Component Number	Item	Transverse	Orientation	X_Add (FT)	Y_Add (FT)	Deck Ref
PRIME_MOVER	1	3	TE_H800	STBD	LONGITUDINAL	5	3.2270341	0
PRIME_MOVER	1	4	5R5_75B	PORT	LONGITUDINAL	0	3	0
PRIME_MOVER	1	5	ABB_MAXSG	PORT	LONGITUDINAL	-8	3	9.5
PRIME_MOVER	1	6	AURORA_481__BASE_12_SW_PUMP	STBD	LONGITUDINAL	-7	4.6934995	0
PRIME_MOVER	1	7	AURORA_481__BASE_12_FIRE_PUMP	STBD	LONGITUDINAL	-13	2.5563779	0

IPS

Reference	Equipment Reference	Component Number	Item	Transverse	Orientation	X_Add (FT)	Y_Add (FT)	Deck Ref
GENERATOR	2	8	PCM4_ABB_ACS_800_5200	STBD	LONGITUDINAL	-2	2.5	9.5
GENERATOR	2	9	PCM1_2400	PORT	LONGITUDINAL	-8	3	9.5
PRIME_MOVER	1	10	PCM1_2400	STBD	LONGITUDINAL	5	3	9.5
PRIME_MOVER	1	11	PCM2_2400	STBD	LONGITUDINAL	0	3	9.5

COMPARTMENT DATA

Selection: USER_DEFINE

Addition	Parameter	User Defined (FT)
2	OMR1_Length_Min	-10.30107111
-4	OMR1_Length_Max	-53.93094491
-3	OMR1_Width_Min	-8.878538841
3	OMR1_Width_Max	21.48162731
	OMR1_Height_Min	0
	OMR1_Height_Max	20.5

OMR1_Length	43.6298738
OMR1_Width	30.36016615
OMR1_X_Centroid	-32.11600801
OMR1_Y_Centroid	6.301544235
OMR1_Z_Centroid	19.25

The vertical arrangement of the OMR accounts for the ESSDT input. Since the average deck height is 9.5 ft, the height references are altered to allow the user within ESSDT to match this equipment space with the deck heights in the hull.

Once the data entry is complete, click the Calculate button at the bottom left of the worksheet to lock-in the values. The result of the data entry should look like Figure A-31.

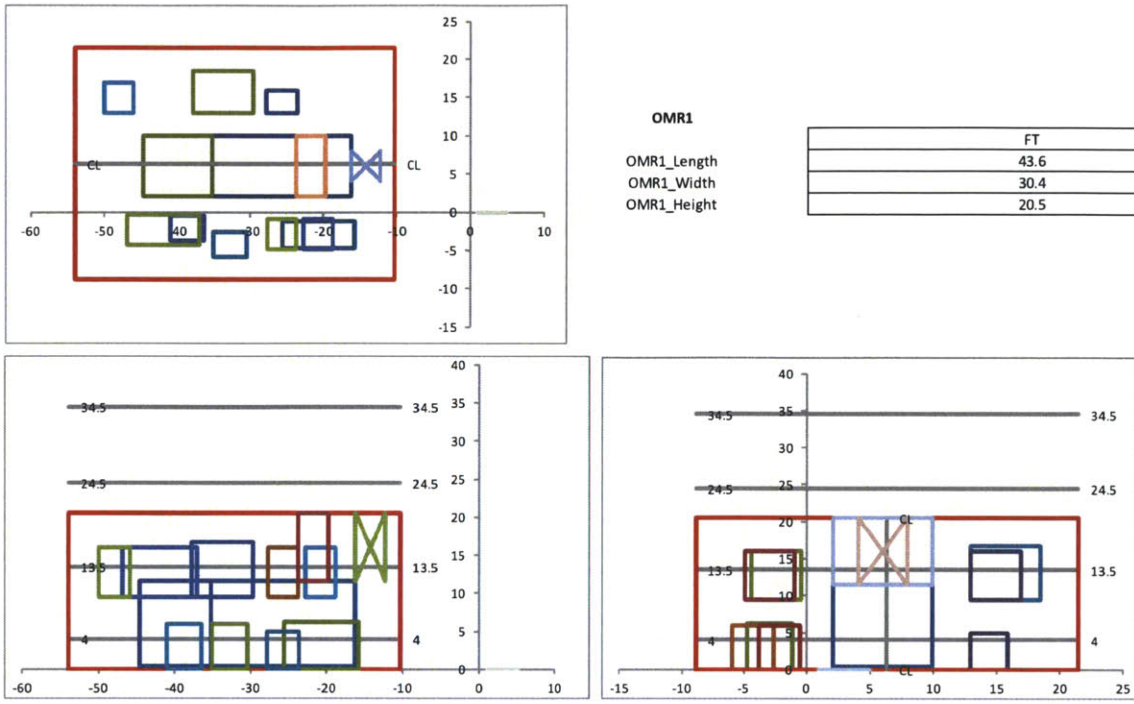


Figure A-31: OMR1 Tutorial Arrangement

The same procedure is conducted for the next compartment after the arrangement is satisfied.

17. Locate Compartment 6 Sheet: AMR2

The following list of equipment should appear in Compartment Sheet 6 for AMR2:

Equipment Type	Item
SEA_WATER_COOLING_SYSTEM	AURORA_481__BASE_12_SW_PUMP
FIRE_SYSTEM	AURORA_481__BASE_12_FIRE_PUMP
SS_DC_TO_DC_PCM	PCM1_2400
SS_DC_TO_DC_PCM	PCM1_2400
SS_DC_TO_AC_INV	PCM2_2400

The list above was generated based on the equipment selections made earlier in the tutorial. Following the compartment sheet description of Section 12, input the following data into the yellow cells only:

AUX

Reference	Equipment Reference	Component Number	Item	Transverse	Orientation	X_Add (FT)	Y_Add (FT)	Deck Ref
		1	AURORA_481__BASE_12_SW_PUMP	CL	LONGITUDINAL	2	2	4
		2	AURORA_481__BASE_12_FIRE_PUMP	CL	LONGITUDINAL	-4	2	4

IPS

Reference	Equipment Reference	Component Number	Item	Transverse	Orientation	X_Add (FT)	Y_Add (FT)	Deck Ref
		3	PCM1_2400	CL	LONGITUDINAL	-5	8	24.5
		4	PCM1_2400	CL	LONGITUDINAL	5	-4	4
		5	PCM2_2400	CL	LONGITUDINAL	-4	-4	4

COMPARTMENT DATA

Selection: USER_DEFINE

Addition	Parameter	User Defined (FT)
3	AMR2_Length_Min	-10
-3	AMR2_Length_Max	10
-3	AMR2_Width_Min	-15
3	AMR2_Width_Max	15
	AMR2_Height_Min	0
	AMR2_Height_Max	13.5

AMR2_Length	20
AMR2_Width	30
AMR2_X_Centroid	0
AMR2_Y_Centroid	0
AMR2_Z_Centroid	6.75

AMR2 is a null compartment added to increase the separation between MMR1 and MMR2. The only items present are the fire pump, sea water cooling system pump, and IPS modules. The overall dimensions of the space are estimated. For more information regarding the additional compartment see Chapter 3 Section 3.6.3.

Once the data entry is complete, click the Calculate button at the bottom left of the worksheet to lock-in the values. The result of the data entry should look like Figure A-32.

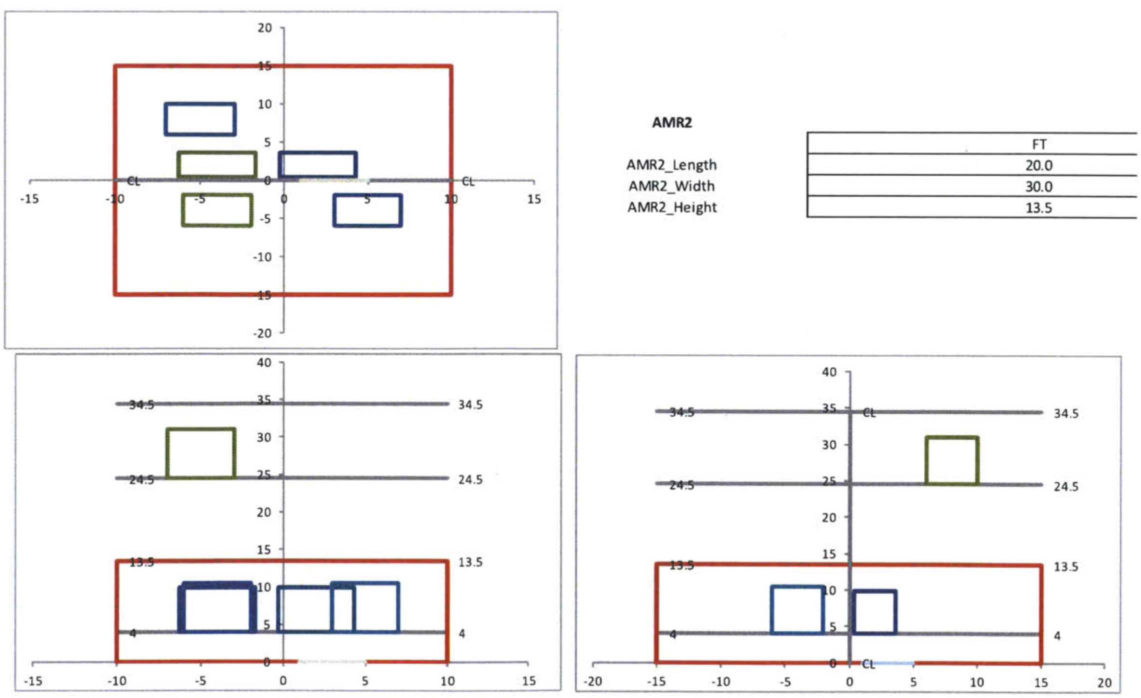


Figure A-32: AMR2 Tutorial Arrangement

From this point, the equipment arrangement portion is complete.

18. Expand Section 12) MACHINERY BLOCK ORDER

The arrangement of all MMR and AMR compartments are compiled into this section. The composition of the machinery block only comprises of MMRs and AMRs. OMRs are treated as a payload entity within ESSDT and are not included in the machinery stack-up block. The ordering for this arrangement was based on the Figure A-14 and is as follows:

1. AMR1
2. MMR1
3. AMR2
4. MMR2

The user should enter the sequencing numbers to the corresponding compartments. Entering the number sequence above allows the user consecutively order the blocks from right to left, resulting in Figure A-33.

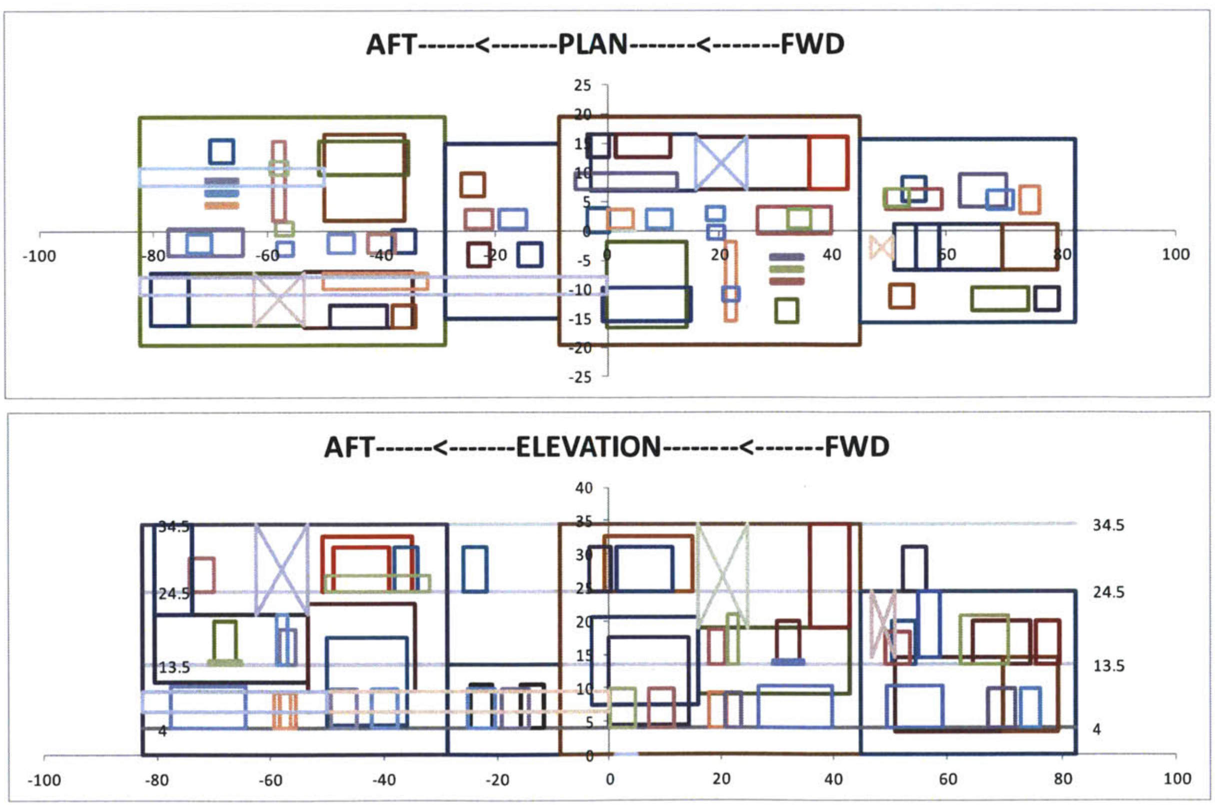


Figure A-33: Machinery Block

The sequencing allows for rapid repositioning of entire compartments to evaluate positioning tradeoffs; however, repositioning the compartments may require reorientation of equipment to satisfy the stack-up unit arrangement. The total stack-up unit is also symmetric about the origin (x=0, y=0, z=0), meaning the positive value of the forward most bulkhead is equal the negative value of the aft most bulkhead. This positioning was implemented for direct integration with ESSDT. The total length and maximum width of the unit in the figure above should be as follows:

MMR_TOTAL_STACKUP_LENGTH (FT)	164.9
MMR_MAX_WIDTH (FT)	39.3

The purpose of viewing this arrangement is to visually evaluate the system as a unit comprised of consecutive compartments. It also allows the user to view the shafting and intake/exhaust routing impacts. Compartments following a compartment containing a propulsion motor, such as AMR2 and MMR2 in Figure A-33, influence the position of the equipment. If changes must be made, the user must return to the compartment sheets to implement a change to the arrangement. In this case, the starboard most equipment in AMR2 was moved inboard and the vertical height of the prime mover in MMR2 was also increased to account for the shafting. Also the positioning of prime movers will also influence the intake and exhaust routing, especially when two or more prime movers share a common bulkhead.

19. Expand 13) SHAFTING AND PROPELLER DEFINITION

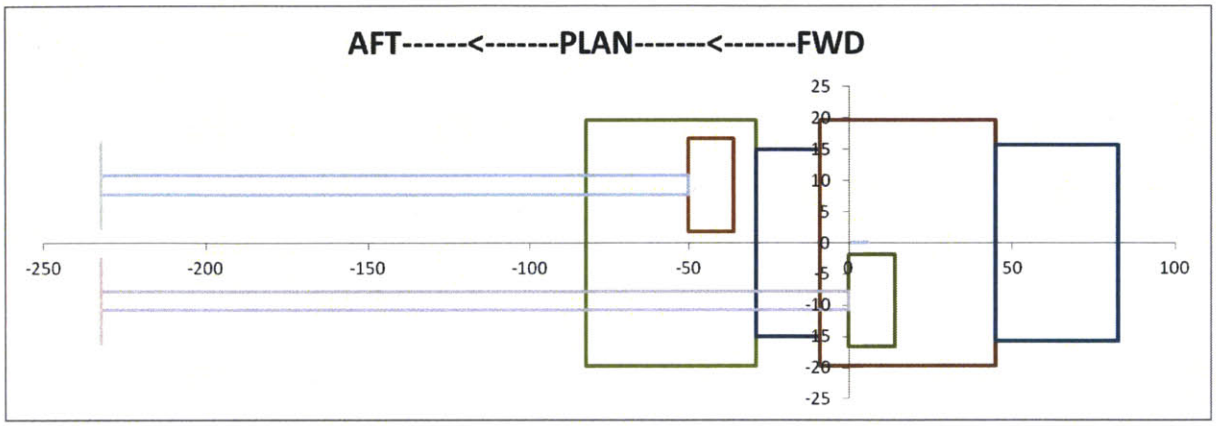
After the stack-up unit definition is satisfied, the user must evaluate the shaft length and diameter of the propeller. Since the hull form is absent from the IPSDM process, the shaft length is estimated by applying an additional length factor. The shaft length should be adjusted after determining the overall length of the vessel in ESSDT.

The diameter is also estimated based on the spacing of the propulsion motors. An additional factor can be applied to increase or decrease the propeller diameter estimate. Again, this value should be reevaluated after the hull form selection and shaft depression angle determination within ESSDT.

For the purpose of this exercise, enter the following:

- Shafting Length Addition = 150 ft
- Diameter Factor = 4.5 ft

Inputting those factors results in Figure A-34.



SHAFTING LENGTH ADD (FT)
150

	LENGTH (FT)
CONVERTEAM_IPS_AIM_19MW_MOTOR_SHAFT_MMR1	232.4092914
CONVERTEAM_IPS_AIM_19MW_MOTOR_SHAFT_MMR2	182.3648294

PROPELLER	POSITION (FT)	DIAMETER FACTOR (FT)	EST. MAX DIAMETER (FT)
CONVERTEAM_IPS_AIM_19MW_MOTOR_SHAFT_MMR1_PROP	-9.270997377	4.5	13.77099738
CONVERTEAM_IPS_AIM_19MW_MOTOR_SHAFT_MMR2_PROP	9.270997377	4.5	13.77099738

Figure A-34: Shafting and Propellers

20. Expand 14) STACK DEFINITION

With the equipment and compartment locations determined, the user must define the route of the exhaust stacks. The intakes are assumed to travel vertically and not deviate from the prime mover; therefore, only an additional height factor is required to estimate the overall height of the intake. The intake routing convention applies to gas turbine prime movers. The exhaust routing requires the user to enter eight unique points. The position of the points generates a polyline that is then swept with the exhaust diameter of the prime mover within GRC Paramarine. The unique data points are also required for GRC Paramarine.

The stack definition section is split into four parts: the stack definition for the machinery block, OMR1, OMR2, and OMR3. IPSDMv1.0 automatically separates the prime movers from the PGM selection and positions the data within each section. The user is provided the first point based on the position of the equipment. The remaining seven points must be assigned by the user. For this exercise, assign the following unique points for the machinery block:

EXHAUST_1	X (FT)	Y (FT)	Z (FT)
RR_501K34_3_MW_EXHAUST_SS_AMR1_p_2	48.79003	-2.7874	57.25
RR_501K34_3_MW_EXHAUST_SS_AMR1_p_3	48.79003	0	57.25
RR_501K34_3_MW_EXHAUST_SS_AMR1_p_4	42	0	57.25
RR_501K34_3_MW_EXHAUST_SS_AMR1_p_5	30	0	57.25
RR_501K34_3_MW_EXHAUST_SS_AMR1_p_6	30	0	67.25
RR_501K34_3_MW_EXHAUST_SS_AMR1_p_7	30	0	77.25
RR_501K34_3_MW_EXHAUST_SS_AMR1_p_8	30	0	97.25

EXHAUST_2	X (FT)	Y (FT)	Z (FT)
GE_LM2500_25_1MW_EXHAUST_PD_MMR1_p_2	20.33133	11.729	57.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR1_p_3	20	0	62.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR1_p_4	20	0	67.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR1_p_5	20	0	72.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR1_p_6	20	0	77.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR1_p_7	20	0	82.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR1_p_8	20	0	97.25

EXHAUST_3	X (FT)	Y (FT)	Z (FT)
GE_LM2500_25_1MW_EXHAUST_PD_MMR2_p_2	-57.9612	-11.729	57.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR2_p_3	-57.9612	-11.729	57.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR2_p_4	-55	0	57.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR2_p_5	-55	0	77.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR2_p_6	-55	0	87.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR2_p_7	-55	0	92.25
GE_LM2500_25_1MW_EXHAUST_PD_MMR2_p_8	-55	0	97.25

Assigning an intake height adjustment of 30 results in Figure A-35.

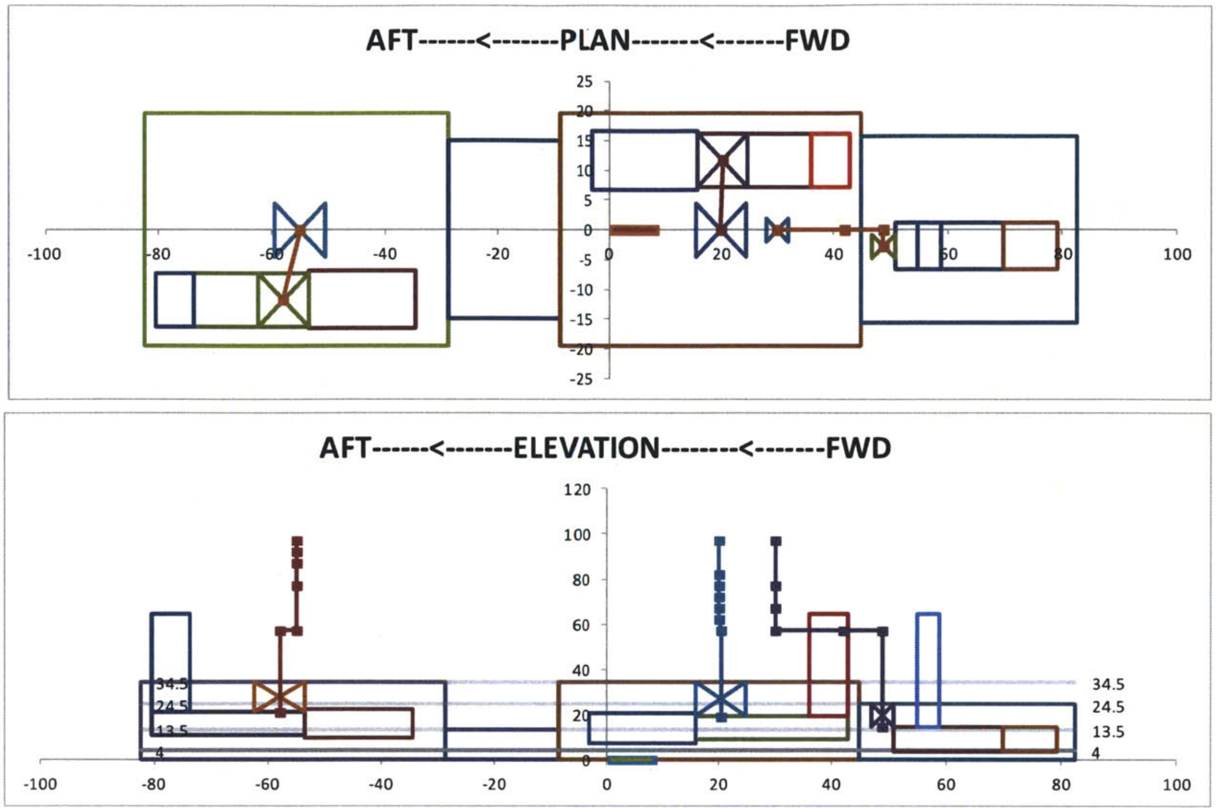


Figure A-35: Stack Routing

The same method is applied to the OMRs. For this exercise, assign the following values for OMR1:

DEFAULT HEIGHT ADD (FT) 20

EXHAUST_1	X (FT)	Y (FT)	Z (FT)
OMR1_RR_501K34_3_MW_EXHAUST_SS_OMR1_p_1	17.86286	-0.30154	11.54462
OMR1_RR_501K34_3_MW_EXHAUST_SS_OMR1_p_2	17.86286	-0.30154	21.54462
OMR1_RR_501K34_3_MW_EXHAUST_SS_OMR1_p_3	15	0	31.54462
OMR1_RR_501K34_3_MW_EXHAUST_SS_OMR1_p_4	15	0	34.54462
OMR1_RR_501K34_3_MW_EXHAUST_SS_OMR1_p_5	15	0	37.54462
OMR1_RR_501K34_3_MW_EXHAUST_SS_OMR1_p_6	15	0	40.54462
OMR1_RR_501K34_3_MW_EXHAUST_SS_OMR1_p_7	15	0	43.54462
OMR1_RR_501K34_3_MW_EXHAUST_SS_OMR1_p_8	15	0	46.54462

Resulting in Figure A-36:

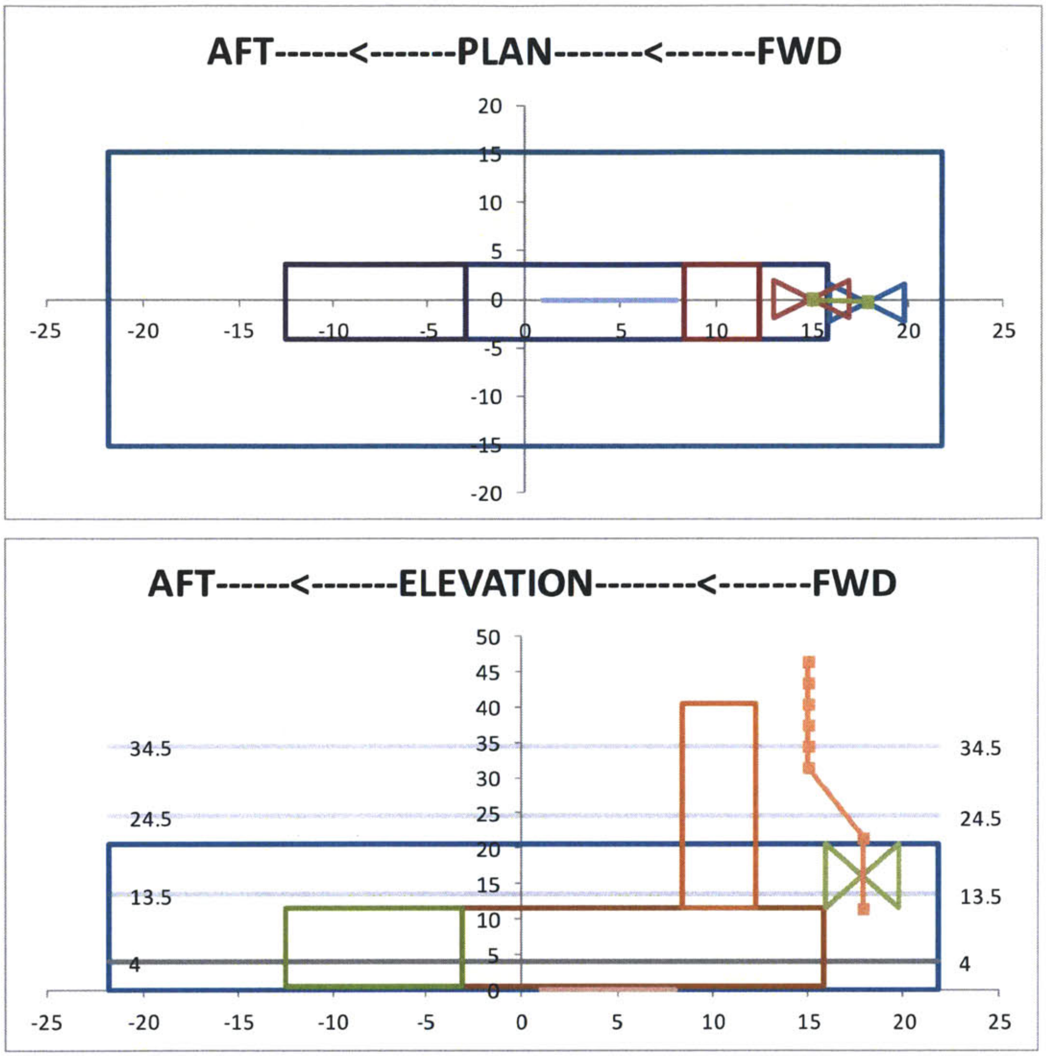


Figure A-36: OMR1 Stack Routing

21. Expand 15) SERVICE HIGHWAY DEFINITION

The addition of the service highway definition was added late within IPSDMv1.0. Even though this section does not directly interface with ESSDT, it serves as platform for future expansion into the design of the distribution system. With the equipment arranged, the user can determine a path for port and starboard service highways through the machinery compartments. The service highways are envisioned to act as central pathways for cabling and piping.

The service highways are approximated by straight line segments within each compartment. Assign the following data to define the service highway:

		PORT		STARBOARD	
		Y (FT)	Z (FT)	Y (FT)	Z (FT)
COMPARTMENT_1	START_1	10	30	-10	10.5
COMPARTMENT_2	START_2	5	30	-17	10.5
COMPARTMENT_3	START_3	5	30	-5	10.5
COMPARTMENT_4	START_4	10	30	-5	10.5

The result of the data entry is depicted in Figure A-37.

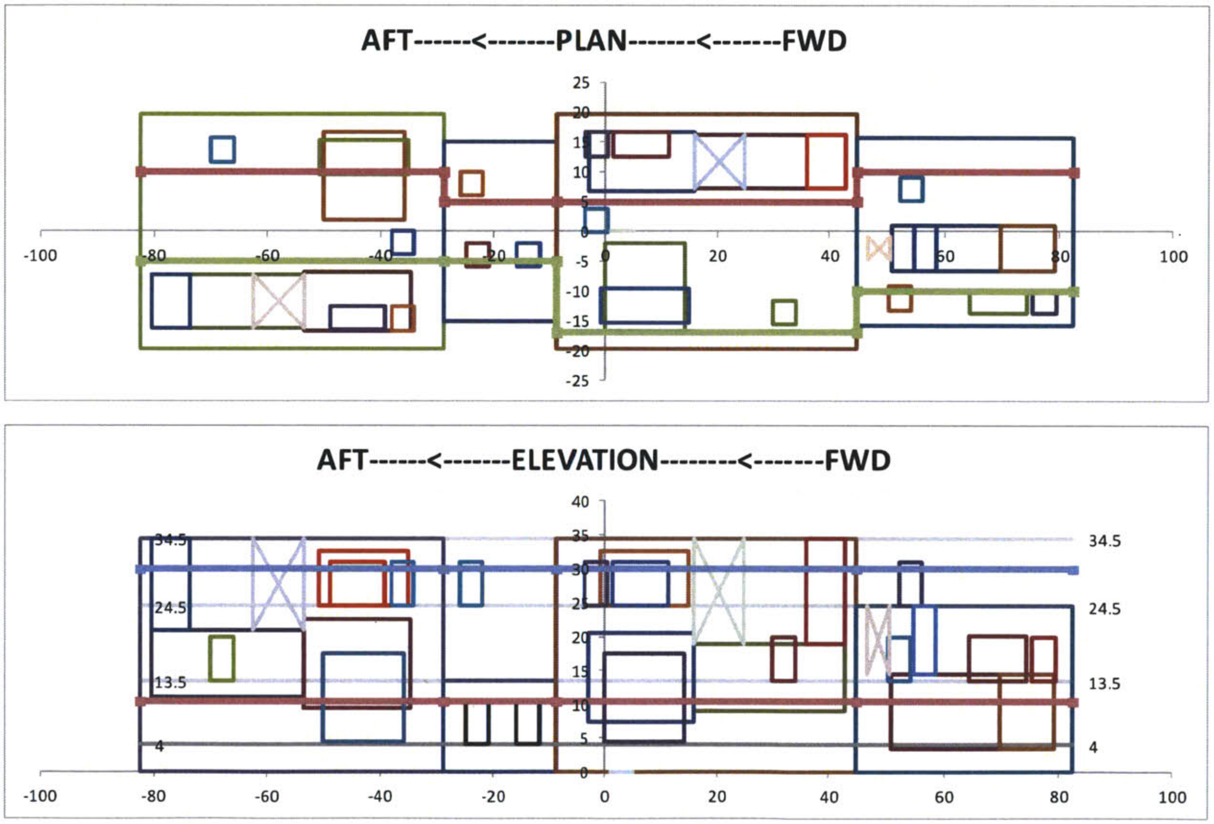


Figure A-37: Service Highways

Note that the port and starboard buses are not only separated transversely, but vertically as well. Ideally the service highway data from this section would be implemented with ESSDT, but does not within IPSDMv1.0.

22. Expand 16) WEIGHT ESTIMATION SUMMARY

The weight estimation procedure is discussed in Chapter 3 Section 3.7. The result of the weight estimation is:

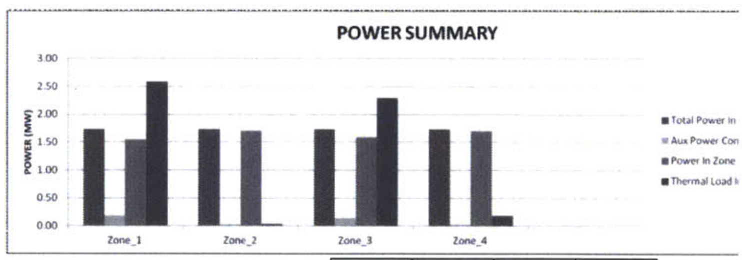
ESWBS	Weight (LT)
GROUP_2	407.0
GROUP_3	105.9
GROUP_5	10.6
TOTAL (LT)	**523.6**

The Input Sheet only depicts the weight estimation summary; however, should the user prefer to see the analysis, a hyperlink to the Weight Summary sheet is provided.

23. Section 17) DESIGN SUMMARY

The Design Summary section provides high level information of the IPS design. It provides the overall dimensions of the machinery block, the OMRs, and various power information. It also provides a zonal summary of the compartments in the form of power supply, demand, and thermal loads. The following summary for tutorial design should be as follows:

SUMMARY	
Machinery Block Length (ft)	164.9
OMR1 Length (ft)	43.6
OMR2 Length (ft)	
OMR3 Length (ft)	
Maximum Width (ft)	39.3
Maximum Height (ft)	34.5
Total Installed Brake Power (MW)	56.7
Total Distributable Power (MW)	49.8
Total Required Propulsion Power (MW)	42.8
Total Shaft Power (MW)	38.0
Net Power Available (MW)	6.5
Total Auxiliary Power at Max Demand (MW)	0.4
Estimated Maximum Cooling Required (MW)	5.1
Estimated Total Weight (LT)	523.6



	Zone_1	Zone_2	Zone_3	Zone_4
Total Power In Zone (MW)	1.73	1.73	1.73	1.73
Aux Power Consumption (MW)	0.19	0.03	0.15	0.03
Power In Zone Remaining (MW)	1.54	1.70	1.58	1.70
Thermal Load In Zone (MW)	2.58	0.04	2.29	0.18

24. Export Design Data

Once the design is complete, the data can be exported to a database for use within ESSDT. Within IPSDMv1.0, the export process must be performed manually. The user must locate the Final Data Sheet, copy the contents of the entire sheet, and paste the contents into a new sheet within an external Machinery Summary MS Excel database. Within that database, the user must name the new IPS design worksheet and copy the exact name to Machinery Summary worksheet. This procedure allows ESSDT to extract the machinery information for use in subsequent analysis.

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APPENDIX B: CASE STUDY VARIANT 1 AND 2 EQUIPMENT LISTS

Number	Variant 1	
	Equipment	Location
1	GT_501_K	AMR1
2	501_K_GENERATOR	AMR1
3	ENGINE_FUEL_SYSTEM	AMR1
4	START_AIR_SYSTEM	AMR1
5	BUS_SWITCHGEAR	AMR1
6	SW_COOL_SYSTEM	AMR1
7	FIRE_SYSTEM	AMR1
8	PCM4	AMR1
9	PCM1	AMR1
10	PCM1	AMR1
11	PCM2	AMR1
12	GE_LM2500_PLUS	MMR1
13	GE_LM2500_PLUS	MMR1
14	LM2500_PLUS_GENERATOR	MMR1
15	LM2500_PLUS_GENERATOR	MMR1
16	GENERATOR_LUBE_SYSTEM	MMR1
17	ENGINE_FUEL_SYSTEM	MMR1
18	START_AIR_SYSTEM	MMR1
19	BUS_SWITCHGEAR	MMR1
20	ENGINE_LUBE_SYSTEM	MMR1
21	GENERATOR_LUBE_SYSTEM	MMR1
22	ENGINE_FUEL_SYSTEM	MMR1
23	START_AIR_SYSTEM	MMR1
24	BUS_SWITCHGEAR	MMR1
25	ENGINE_LUBE_SYSTEM	MMR1
26	SW_COOL_SYSTEM	MMR1
27	FIRE_SYSTEM	MMR1
28	PCM4	MMR1
29	PCM4	MMR1
30	PCM1	MMR1
31	PCM1	MMR1
32	PCM2	MMR1
33	42MW_MOTOR	MMR2
34	PCM_MOTOR	MMR2
35	PMM_MOTOR_LUBE_SYSTEM	MMR2
36	BRAKING_RESISTOR	MMR2
37	BRAKING_RESISTOR	MMR2
38	BRAKING_RESISTOR	MMR2

39	SW_COOL_SYSTEM	MMR2
40	FIRE_SYSTEM	MMR2
41	PCM1	MMR2
42	PCM1	MMR2
43	PCM2	MMR2
44	SW_COOL_SYSTEM	AMR2
45	FIRE_SYSTEM	AMR2
46	PCM1	AMR2
47	PCM1	AMR2
48	PCM2	AMR2
49	42MW_MOTOR	MMR3
50	PCM_MOTOR	MMR3
51	PMM_MOTOR_LUBE_SYSTEM	MMR3
52	BRAKING_RESISTOR	MMR3
53	BRAKING_RESISTOR	MMR3
54	BRAKING_RESISTOR	MMR3
55	SW_COOL_SYSTEM	MMR3
56	FIRE_SYSTEM	MMR3
57	PCM1	MMR3
58	PCM1	MMR3
59	PCM2	MMR3
60	GT_501_K	MMR4
61	GE_LM2500_PLUS	MMR4
62	GE_LM2500_PLUS	MMR4
63	501_K_GENERATOR	MMR4
64	LM2500_PLUS_GENERATOR	MMR4
65	LM2500_PLUS_GENERATOR	MMR4
66	ENGINE_FUEL_SYSTEM	MMR4
67	START_AIR_SYSTEM	MMR4
68	BUS_SWITCHGEAR	MMR4
69	GENERATOR_LUBE_SYSTEM	MMR4
70	ENGINE_FUEL_SYSTEM	MMR4
71	START_AIR_SYSTEM	MMR4
72	BUS_SWITCHGEAR	MMR4
73	ENGINE_LUBE_SYSTEM	MMR4
74	GENERATOR_LUBE_SYSTEM	MMR4
75	ENGINE_FUEL_SYSTEM	MMR4
76	START_AIR_SYSTEM	MMR4
77	BUS_SWITCHGEAR	MMR4
78	ENGINE_LUBE_SYSTEM	MMR4
79	SW_COOL_SYSTEM	MMR4

80	FIRE_SYSTEM	MMR4
81	PCM4	MMR4
82	PCM4	MMR4
83	PCM4	MMR4
84	PCM1	MMR4
85	PCM1	MMR4
86	PCM2	MMR4
87	GT_501_K	OMR1
88	501_K_GENERATOR	OMR1
89	ENGINE_FUEL_SYSTEM	OMR1
90	START_AIR_SYSTEM	OMR1
91	BUS_SWITCHGEAR	OMR1
92	SW_COOL_SYSTEM	OMR1
93	FIRE_SYSTEM	OMR1
94	PCM4	OMR1
95	PCM1	OMR1
96	PCM1	OMR1
97	PCM2	OMR1

Number	Variant 2	
	Equipment	Location
1	GT_501_K	AMR1
2	501_K_GENERATOR	AMR1
3	ENGINE_FUEL_SYSTEM	AMR1
4	START_AIR_SYSTEM	AMR1
5	BUS_SWITCHGEAR	AMR1
6	SW_COOL_SYSTEM	AMR1
7	FIRE_SYSTEM	AMR1
8	PCM4	AMR1
9	PCM1	AMR1
10	PCM1	AMR1
11	PCM2	AMR1
12	GE_LM6000	MMR1
13	GE_LM6000	MMR1
14	LM6000_GENERATOR	MMR1
15	LM6000_GENERATOR	MMR1
16	GENERATOR_LUBE_SYSTEM	MMR1
17	ENGINE_FUEL_SYSTEM	MMR1
18	START_AIR_SYSTEM	MMR1
19	BUS_SWITCHGEAR	MMR1
20	ENGINE_LUBE_SYSTEM	MMR1

21	GENERATOR_LUBE	MMR1
22	ENGINE_FUEL_SYSTEM	MMR1
23	START_AIR_SYSTEM	MMR1
24	BUS_SWITCHGEAR	MMR1
25	ENGINE_LUBE_SYSTEM	MMR1
26	SW_COOL_SYSTEM	MMR1
27	FIRE_SYSTEM	MMR1
28	PCM4	MMR1
29	PCM4	MMR1
30	PCM1	MMR1
31	PCM1	MMR1
32	PCM2	MMR1
33	28MW_MOTOR	MMR2
34	28MW_MOTOR	MMR2
35	PCM_MOTOR	MMR2
36	PMM_Power_Filter	MMR2
37	PMM_MOTOR_LUBE_SYSTEM	MMR2
38	BRAKING_RESISTOR	MMR2
39	BRAKING_RESISTOR	MMR2
40	BRAKING_RESISTOR	MMR2
41	PCM_MOTOR	MMR2
42	PMM_Power_Filter	MMR2
43	PMM_MOTOR_LUBE_SYSTEM	MMR2
44	BRAKING_RESISTOR	MMR2
45	BRAKING_RESISTOR	MMR2
46	BRAKING_RESISTOR	MMR2
47	SW_COOL_SYSTEM	MMR2
48	FIRE_SYSTEM	MMR2
49	PCM1	MMR2
50	PCM1	MMR2
51	PCM2	MMR2
52	GT_501_K	OMR1
53	501_K_GENERATOR	OMR1
54	ENGINE_FUEL_SYSTEM	OMR1
55	START_AIR_SYSTEM	OMR1
56	BUS_SWITCHGEAR	OMR1
57	SW_COOL_SYSTEM	OMR1
58	FIRE_SYSTEM	OMR1
59	PCM4	OMR1
60	PCM1	OMR1
61	PCM1	OMR1

62	PCM2	OMR1
63	POD_9_8MW_MOTOR	OMR2
64	POD_9_8MW_MOTOR	OMR2
65	PCM_POD	OMR2
66	PMM_Power_Filter	OMR2
67	PMM_MOTOR_LUBE_SYSTEM	OMR2
68	BRAKING_RESISTOR	OMR2
69	BRAKING_RESISTOR	OMR2
70	BRAKING_RESISTOR	OMR2
71	PCM_POD	OMR2
72	PMM_Power_Filter	OMR2
73	PMM_MOTOR_LUBE_SYSTEM	OMR2
74	BRAKING_RESISTOR	OMR2
75	BRAKING_RESISTOR	OMR2
76	BRAKING_RESISTOR	OMR2
77	PCM2	OMR2